ALUMINUM IN MODERN ARCHITECTURE VOLUME II

ALUMINUM IN MODERN ARCHITECTURE VOLUME II

Engineering Design and Detail

by PAUL WEIDLINGER

"The use of aluminum has incredibly changed since it was a rare metal on a par with gold. Now that structures including bridges are built with it, and aluminum airplanes are a prime source of instruction to the building industry, aluminum is a subject for careful engineering.

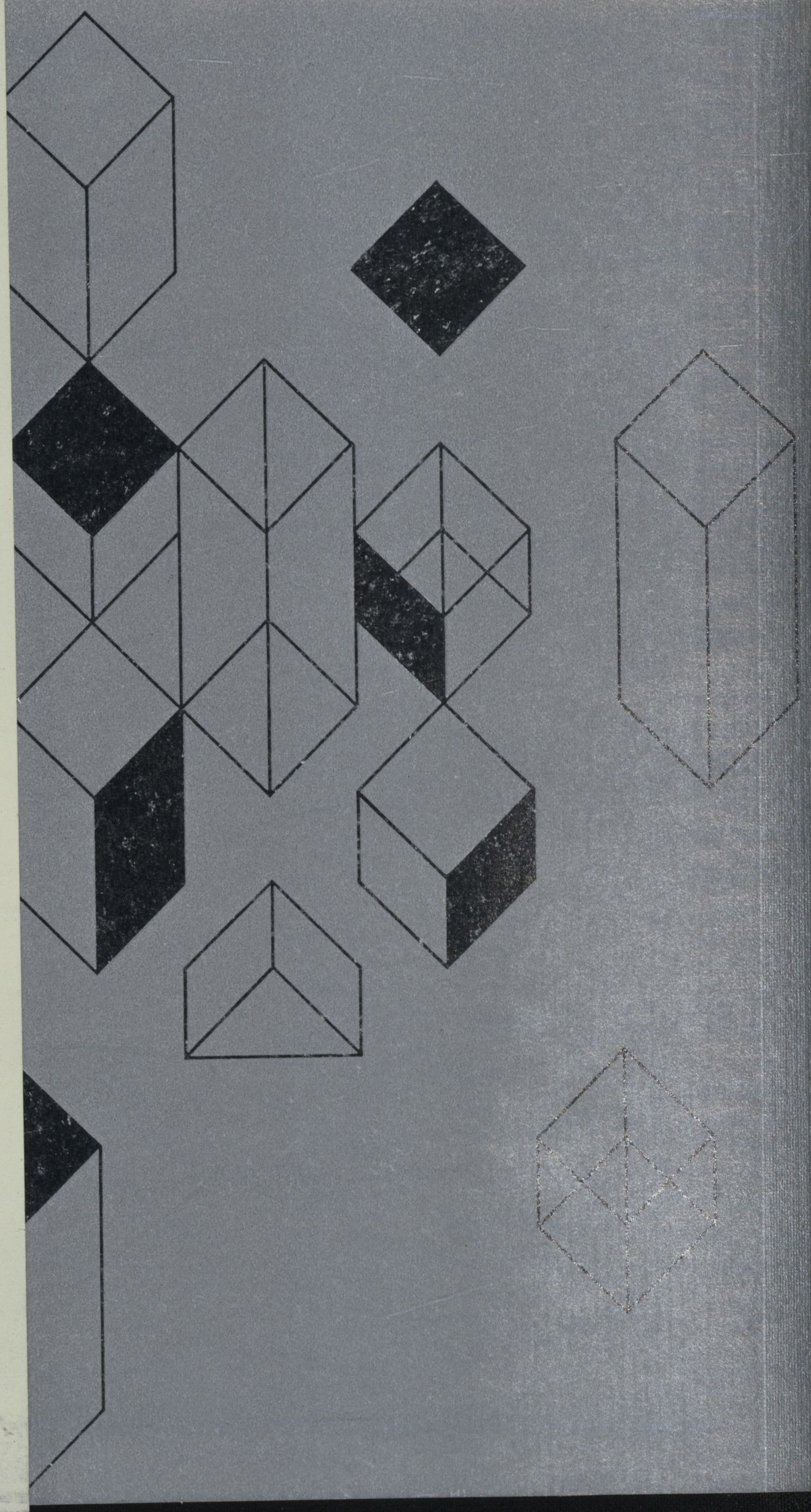
"Volume II of Aluminum in Modern Architecture is edited by Paul Weidlinger, one of that small group of truly creative building engineers in the U. S. that is endowed with esthetic insight as well as engineering skill.

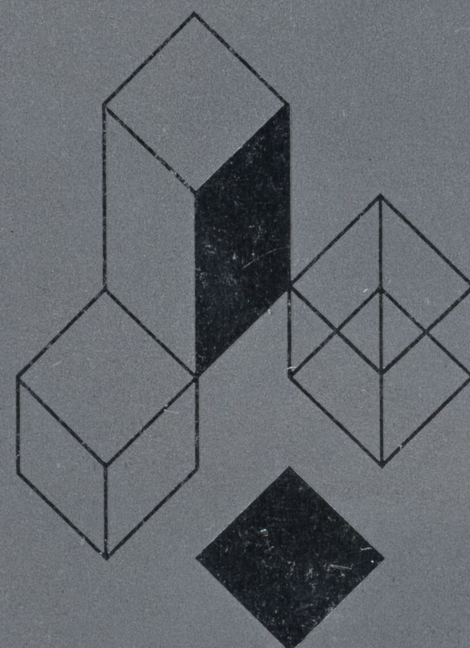
"The part that is likely to get most attention first is the part on joints and connections. 'At present there are no generally accepted standardized connections in structural aluminum. Thus design is time consuming compared to conventional materials.' The book goes a long way toward supplying a full complement of these time conserving needs.

"Yet the more readers penetrate from the back to the front of the book the better. For this is a rare kind of engineering book for the building industry to have. It treats the building field to the kind of rounded knowledge which industries like aviation habitually expect, but building rarely gets. The book deals with everything pertaining to aluminum; its mining, its processing, its fabrication, its qualities under different conditions of use, and the various classification systems like the classification of alloys.

"The publication of this volume is in fact a mark of the gradual maturing of the building industry as a modern industry, and the maturing also of corporate procedures among our big primary producers. The Reynolds Metals Company, a company that had its origin in fabrication rather than production, here tests a modern thesis. Leadership can be achieved by a corporation which masters communication. Moreover the furnishing

continued on back flap





92'

ALUMINUM IN MODERN ARCHITECTURE *Volume II*

Engineering Design and Details

by PAUL WEIDLINGER

Companion to Aluminum in Modern Architecture Volume I—Buildings

Produced by John Peter Associates

Published by REYNOLDS METALS COMPANY, Louisville, Kentucky

Distributed by Reinhold Publishing Corporation, New York, New York

Louisville, Kentucky
Printed in U.S.A.
LIBRARY OF CONGRESS NUMBER 56-6114

TO THE BUILDING INDUSTRY:

Volume II is an engineering reference book, companion to Aluminum in Modern Architecture, Volume I.

This book was especially prepared by one of America's outstanding engineers, Paul Weidlinger. Reynolds Metals Company feels fortunate to have his experienced services in preparing an authoritative work on this modern metal.

The scope of the book, the most comprehensive ever published on this subject, can be appreciated from the contents page. From development and theory to application and specification, with over twelve hundred illustrations, this volume should provide the answers for working designers. It is our purpose to offer the reader both practical help on the many aluminum materials as well as an understanding of the possibilities of aluminum in architecture.

REYNOLDS METALS COMPANY

The author acknowledges the help and cooperation of the Editorial and Engineering staffs of Reynolds Metals Company for the editing, review and checking of the manuscript. This volume covers a wide range of topics and is the result of the cooperation of specialists in many fields.

The author is especially indebted to: Mr. L. L. Rado, A.I.A. for the manuscript of Chapter 7 (Architectural Design and Details) and for the supervision of the preparation of all illustrations. Acknowledgments are also due for their assistance to: Mr. Herbert L. Alexander, Jr.M, A.S.C.E. (Chapter 6); Mr. Robert R. Jones, Consulting Engineer (Chapter 7); and Mr. Fred Blum, (Coordination and Editing).

CONTENTS

Walls of aluminum and glass enclosing the vaults of the Lambert St. Louis Airport represent the most popular use of aluminum in architecture today.

This volume is intended as a treatise on architectural engineering, directed to a specific building material: Aluminum. It appears logical to demonstrate contemporary design concepts and methods on this material which itself is the result of up-to-date technological processes.

Up to the present time, contributions and publications on the application of aluminum have come exclusively from scientists and engineers directly or indirectly connected with the development, research or production of this material. The writing of this book has become possible because practical, technical and production problems concerning aluminum alloys are largely solved, standardized products of guaranteed quality are available, and the physical and mechanical characteristics of the material and its behavior under various conditions have been well explored.

As a matter of fact, its importance to the aircraft industry has resulted in a greater quantity of theoretical and empirical data than are available for many traditional building materials. Aluminum as a full-fledged building material has long since left the experimental stage and has passed on safely to the hands of those whose perception and interest lies in applications to building design and construction.

It is generally recognized that contemporary approach puts the greatest emphasis on the fullest use and expression of the pertinent characteristics of building materials. On the other hand, it is still customary to compare materials in terms of isolated technical and economical advantages or drawbacks. One of the aims of this volume is to demonstrate that such comparisons are pernicious: there are, in reality, no unsuitable materials—*only unsuitable applications*. Similarly, drawbacks usually do not pertain to specific types of building materials but rather to those architects or engineers who are unfamiliar with the essential characteristics of the material itself and how to use it effectively.

The history of building gives many instances of disappointing results when new materials were used in accordance with methods applicable to unrelated traditional materials. To help avoid such needless mistakes in the use of aluminum alloys is one of the main purposes of this book. The aim is to make a positive contribution not only to contemporary architecture and engineering, but also to the aluminum industry itself. If mistakes in application can be avoided, it will have beneficial effects far outweighing any momentary advantages which an increased but indiscriminate use of aluminum alloys may represent.

The essential physical and mechanical properties of aluminum alloys are similar in magnitude to those of ferrous metals. On the other hand, the ratio of material to labor cost is substantially different. As a very rough approximation, this ratio for steel structures is about 1 to 2, while it will average 2 to 1 for aluminum structures. The implications on building economics are very important and quite clear: In aluminum it is usually preferable to save on the material even at added labor cost, while for more conventional materials the reverse is true in most instances.

The effect of this can be studied by comparing examples of American and foreign buildings and structures: the greater slenderness and lightness of many foreign structures are not so much the result of better design but rather the end product of the high material-to-labor cost ratio. A similar effect

exists where properly designed aluminum buildings and structures are compared to ones constructed from conventional materials.

The impact of these effects on the design methods to be used and on the resulting architectural expression is of vital importance. In practical terms, this means that the engineer working with aluminum alloys must take full advantage of advanced design methods to obtain maximum efficiency in use of the material. Special attention and refinement of both design and execution always contribute to the quality of the building but these become fully justified economically when using aluminum alloys.

To facilitate this work, this book aims to supply sufficient theoretical information to acquaint engineers and architects with the physical, mechanical and fabricating characteristics of the material pertinent to its application in the building industry. This general background information is covered in the first five chapters. It should be noted that the data presented here are available in a more extensive and different form of presentation in a great number of books, bulletins and brochures concerned with various aspects of aluminum and its alloys. These scattered references are consolidated in these chapters and organized in a form specifically directed to the architect and engineer.

Information of a theoretical nature has been excluded together with certain data of primary concern to those involved in the production or purchase of the material. On the other hand, it was felt desirable to include in a few instances some information which ordinarily would not be considered necessary in a book of this type, such as historical facts, economic data and some detail of the production techniques and manufacturing processes.

In Chapter 4, various types of joints and connections are discussed. These are common for many phases of design and are of importance not only in structural applications, but also in most architectural details and in heating, ventilating, air conditioning, and sanitary installations. Some of the fastening methods described may not be familiar to designers used to working with more conventional materials. They were included because it is felt that special fasteners are of great importance to the design of prefabricated building systems and elements, many of which are produced in aluminum.

Since aluminum is still a relatively new material in the building industry, general background information (which is more or less common knowledge with traditional materials) is included here to enable an intelligent approach to design problems. Along these lines, an analysis of the implications of physical and economic factors in Chapter 5 helps to provide an advance understanding of problems and pitfalls for those who have no previous experience with the material. Generally, these first chapters consist therefore of a compilation of reference data with an analysis of their implications.

The remaining three chapters discuss architectural, structural, heating, ventilating, air conditioning, and sanitary applications. Wherever possible, illustrations in terms of executed examples are given and, where warranted, sample specifications of certain building elements are provided.

In the Appendix, besides much useful related data, structural design and fabrication specifications are reproduced as prepared by the ASCE Committee of the Structural Division on Design in Lightweight Structural Alloys. The existence of such a structural code greatly facilitates the task of the designer and it is hoped that its incorporation into local building ordinances will contribute to the safe and economical use of aluminum alloys. The design examples in Chapters 5 and 6, wherever applicable, are worked out in accordance with the ASCE Codes, with detailed interpretations and discussions where required.

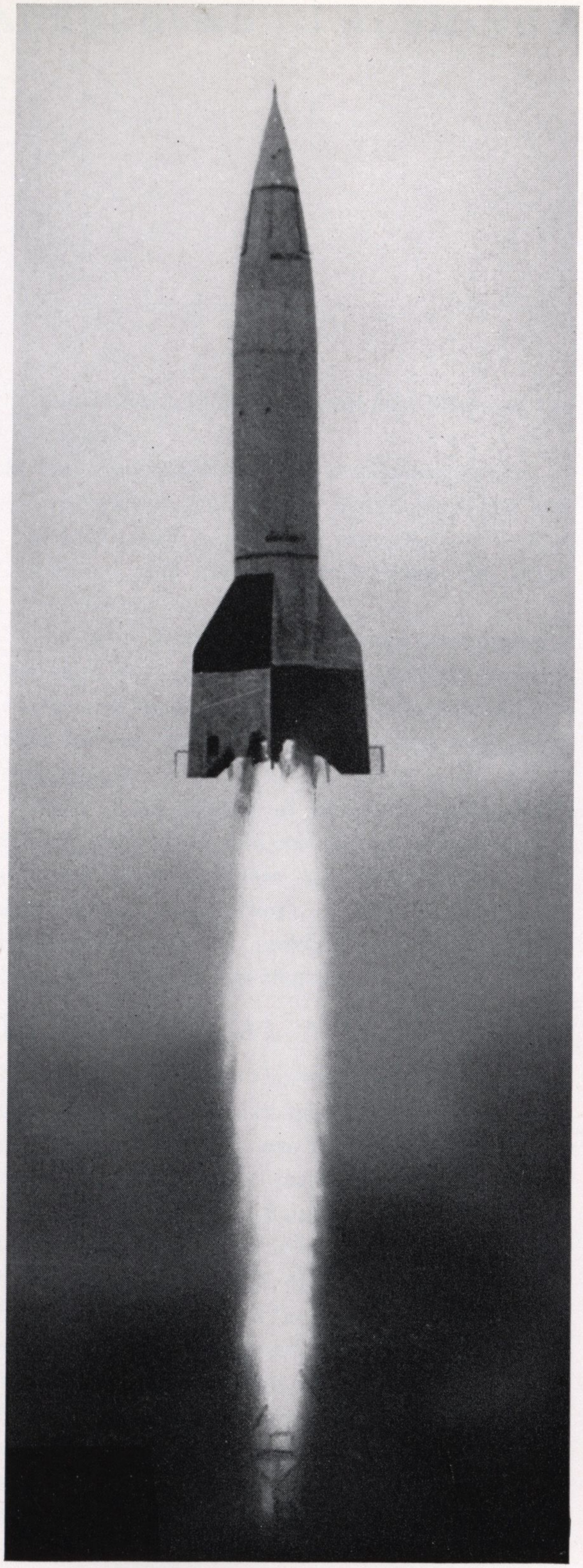
The lack of authoritative code or design specifications in the past has deterred many engineers from attempting structural designs in this material. Even since publication of the ASCE specifications in 1950, the existence of these reports is still not general knowledge. It is hoped that by reproducing these documents in their entirety, together with examples and discussion of their application, further impetus will be given to their widespread use.

At the same time it will be well to remember that while reference tables and specifications are an

important aid to the designer, they should not serve to discourage further developments and imaginative approach to designing. An important factor in the current state of development of the aluminum industry is the unusually large choice offered the architect or engineer not only in the selection of alloys but also in methods of producing and fabricating specific shapes and forms economically to satisfy all requirements. As long as this variety of selection is available, there should be no danger, temptation (or excuse) to freeze design methods to cut-and-dry "handbook" engineering.

The whole development of the aircraft industry should be held up as an inspiring example of fearless and imaginative engineering. From the first aluminum helicopter constructed in 1862 and the first rigid airship built with an aluminum alloy framework and outer covering in 1898 to many of the latest types of aircraft, the incorporation of advanced designs and techniques spelled the unprecedented success of their designers. The contemplation of these airframe solutions and design methods should have a stimulating effect on architects, engineers, and the building industry itself.

With these precedents, it is hoped that readers of this volume will take advantage of these opportunities and this challenge in the interest of progress of contemporary architecture and engineering.



Aeronautical research today provides clues to wider structural use of aluminum in modern architecture tomorrow.

The fullest exploitation of anything new, whether it is an idea, a technique, or a material, demands understanding and imagination. Even under favorable circumstances, many of the potentialities of any new material remain unused and unexplored. This represents a challenge, which any imaginative designer, architect or engineer should want to take up and pursue. The efficient use of aluminum and its alloys in the building industry certainly offers such a challenge.

Fortunately, in this instance, the factual data with respect to physical, chemical, metallurgical and technological properties are available. A surprising amount of practical experience has already been accumulated in the building industry itself and even more in other fields. Because of the importance of aluminum alloys in aircraft design, scientific and engineering information is abundant. It is because this data is available, both scientific and practical, certain definite conclusions can be drawn as to the place of aluminum in the building industry. These might be summarized as follows:

1. Aluminum is a metal generally suitable for buildings and structures.
2. Aluminum should be considered a basic building material in its own right and should not be thought of as a substitute.
3. Its characteristics are sufficiently different from other metals to require different and special methods of design even though sufficient similarities exist to permit the designer to draw, to an extent, on experiences gained from designs in other ferrous and non-ferrous metals.
4. Only the full recognition of these principles can lead to the successful exploitation of the inherent economical and technological advantages of the material.
5. The application of these principles requires an imaginative approach to design problems and should result in solutions characteristic to aluminum and different from those for other materials.

The point of view outlined above presupposes a thorough understanding of the pertinent physical characteristics and technological possibilities. The basis for this is provided in subsequent chapters of this volume.

While a knowledge of historical background, mining, production, and cost factors influencing the price of aluminum does not enter directly into architectural design work, it will contribute to intelligent use of this building material, and so is included briefly in this chapter.

1.1 HISTORICAL NOTES

In 1807 Sir Humphrey Davy suspected the presence of aluminum in clay but despite great efforts and elaborate experiments was unable to obtain it in any form. Twenty six years later, the basic raw material of aluminum, Bauxite, was discovered in the south of France in the village of Les Baux and five years later, in 1825, Hans Christian Oersted, Professor of Physics at the University of Copenhagen, Denmark, produced what appears to have been the first metallic aluminum. Two years later, Friedrich Woehler, a German scientist, produced aluminum as a gray powder. But it was not until 1845 that he was able to transform the powder to solid particles, still hardly larger than a pin head.

Working with these small particles, however,

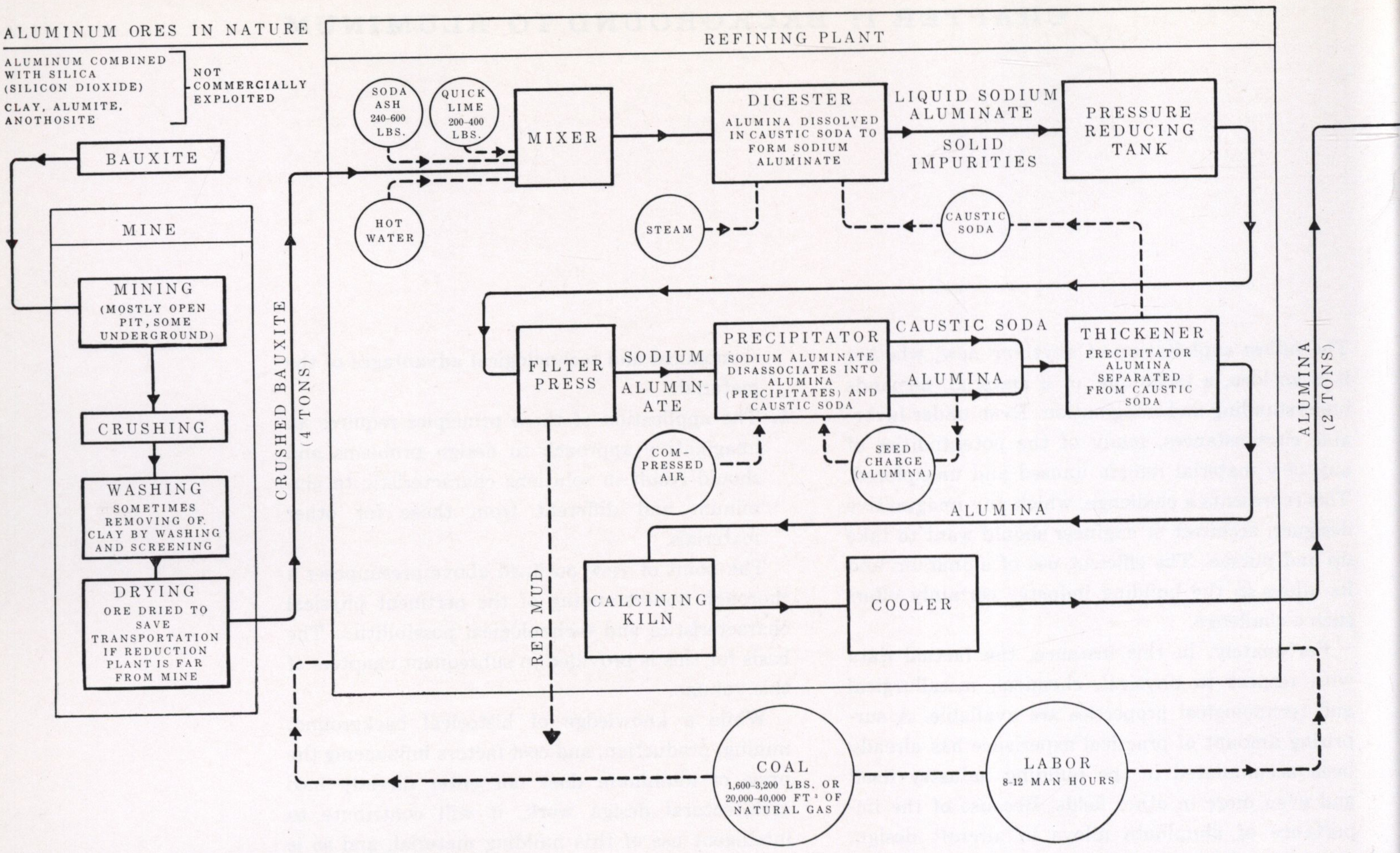


Figure 1-1: Production of 99 percent pure aluminum from Bauxite. (The quantities of materials, labor and electric energy indicated are required to produc

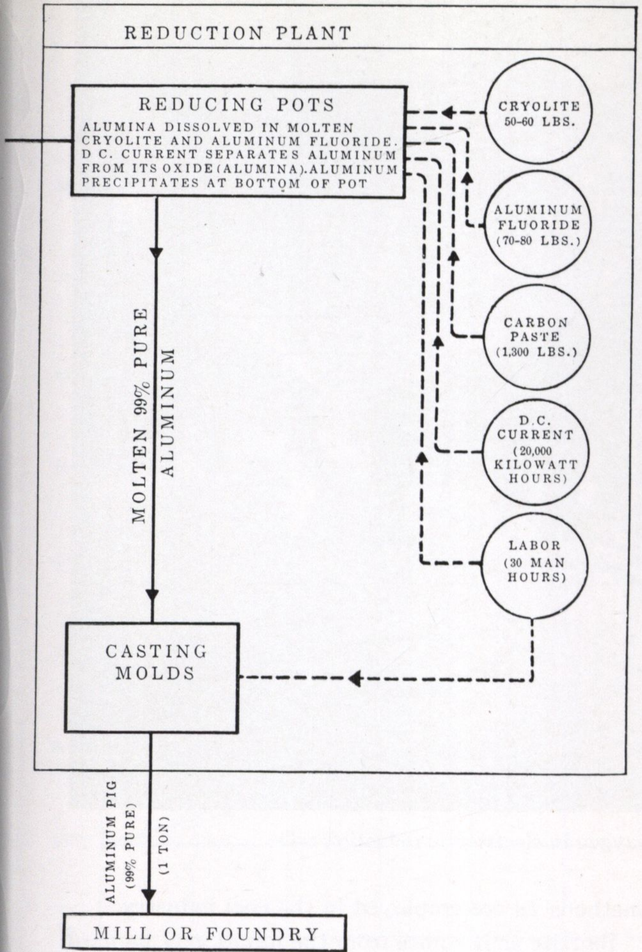
Woehler discovered aluminum's amazingly light weight. He also discovered that it was easy to shape, stable in air, and could be melted with a blowtorch. In 1852, just about 100 years ago, aluminum was so costly to produce that it sold for $545.00 a pound.

In 1854 both the French scientist, Henri Sainte-Claire Deville, and Robert Von Bunsen, Professor of Chemistry at Heidelberg University, working separately, discovered how to isolate aluminum by using sodium instead of potassium, and obtained aluminum of 96–97 percent purity.

Emperor Napoleon III saw the possibilities of the lightweight metal and commissioned Deville to make aluminum armor and helmets for his French Cuirassiers. Deville also produced and displayed several large bars of aluminum at the 1855 Paris Exposition. During this early period, the cost of aluminum was $545.00 a pound (1852). It was more precious than gold or silver. Banquet places for Napoleon's most honored guests were set with forks and spoons of aluminum—lesser guests found gold and silver service at their plates.

In 1856, the American "Mining Magazine" reported that Alfred Monnier of Camden, N. J., had made aluminum in considerable quantity. Specimens were exhibited at the Franklin Institute in Philadelphia. 1884 saw the first application of aluminum in architecture: the aluminum tip, weighing about six pounds, was mounted on top of the Washington monument.

The birth date of the modern aluminum industry is set at 1886. Charles Martin Hall, while a student



1 ton of 99 percent pure aluminum).

at Oberlin College, Oberlin, Ohio, became interested in aluminum and began experimenting to find a better way of producing it. He continued his work after graduation and in 1886 discovered that metallic aluminum could be produced by dissolving alumina in molten cryolite and then passing an electric current through the solution. He applied for a patent which was granted in 1889. Paul T. Heroult, in France, hit upon the same process in the same year. Neither knew of the other's work until Heroult applied for a patent in this country. While Hall obtained a United States patent in 1889, Heroult secured patent rights in France and some other European countries.

As a result of Hall's and Heroult's discovery, the price of aluminum dropped from $11.33 a pound in 1885 to $0.57 a pound in 1892—just 7 years later. In the same year the first aluminum hull for a yacht was built in Switzerland, and the building of the first dirigible with an aluminum frame was begun. From there on this material spread to practically all industries. In 1933 it was first applied to bridge construction. At the present time, aluminum is a basic material of the building industry.

1.2 MINING & PROCESSING*

Modern methods of mining and producing metallic aluminum are of course quite different from the early attempts, even though the basic methods and inherent difficulties remain the same.

ALUMINUM ORE: Sources of aluminum form one twelfth of the earth's crust . . . almost twice as much as iron, the second most plentiful metal. While most common rocks and clays contain aluminum, it is uneconomical to produce the metal from them. Aluminum is commercially obtained only from bauxite, an ore named after the French town of Le Baux where the first high grade aluminum deposits were found. High grade bauxite contains 50–60 percent alumina (aluminum oxide) chemically combined with 15–32 percent water to form a hydrated oxide. The ore also contains 2–7 percent silica, 2–20 percent iron oxide and 2–4 percent titanium oxide, in addition to traces of other minerals.

Most of the world's bauxite deposits are outside the United States, making it necessary for this country to import about three-fourths of its supply. Arkansas is the only state with large deposits of bauxite; 95 percent of the bauxite in the U. S. is mined in that state, the remainder coming from small lower grade deposits in Georgia and Alabama. Foreign sources of bauxite include Surinam (Dutch Guiana), British Guiana, South America and Jamaica.

There are large quantities of other aluminum containing materials in the U. S., but production methods developed up to this time are too costly. These include clay, alumite and anothosite.

Aluminum cannot be produced directly from the ore because of the many impurities present which

* Source: HOW ALUMINUM IS MADE by the Aluminum Association, New York—February 1954

Figure 1-2: Alumina is separated into metallic aluminum and oxygen in electrolytic reduction cells.

would become alloyed with the aluminum. It is, therefore, necessary to first refine the ore, producing alumina (aluminum oxide) of nearly 100 percent purity. The alumina is then reduced to metallic aluminum of better than 99 percent purity.

The reduction of alumina to metallic aluminum is an electrolytic process requiring large amounts of electrical energy. The United States aluminum industry uses more electricity in a day than a city of 60,000 houses in an entire year. In order to obtain 1 ton of metal, 20,000 kilowatt-hours of electric energy are required. It is therefore essential that reduction plants be located near large sources of economical power, such as coal fields, hydroelectric developments, oil or natural gas fields.

MINING TECHNIQUES: Most bauxite deposits occur near the surface and can therefore be mined in open pits . . . to a depth of 100 feet. Deeper deposits employ the same underground mining methods as are employed in the coal industry.

Bauxite as it comes from the mines may be hard as rock or as soft as clay. It is obtained as lumps of all sizes containing varying amounts of clay, sand, and free moisture. After crushing, the clay may be removed by washing and screening. Where the distance from the mine to the reduction plant is long, the ore is first dried to reduce transportation costs. Drying is done in rotary kilns at temperatures of 200 to 250° F. This removes only the free moisture, not the chemically combined water (water of hydration) for which a much higher temperature is required.

REFINING: All commercial refining is done by the Bayer process*, so named after its inventor Karl Josef Bayer.

* Ores containing more than about 10 percent silica cannot be refined economically by the original Bayer process, since for each pound of silica about a pound of caustic soda and a pound of alumina are lost in the red mud along with the silica and other impurities.

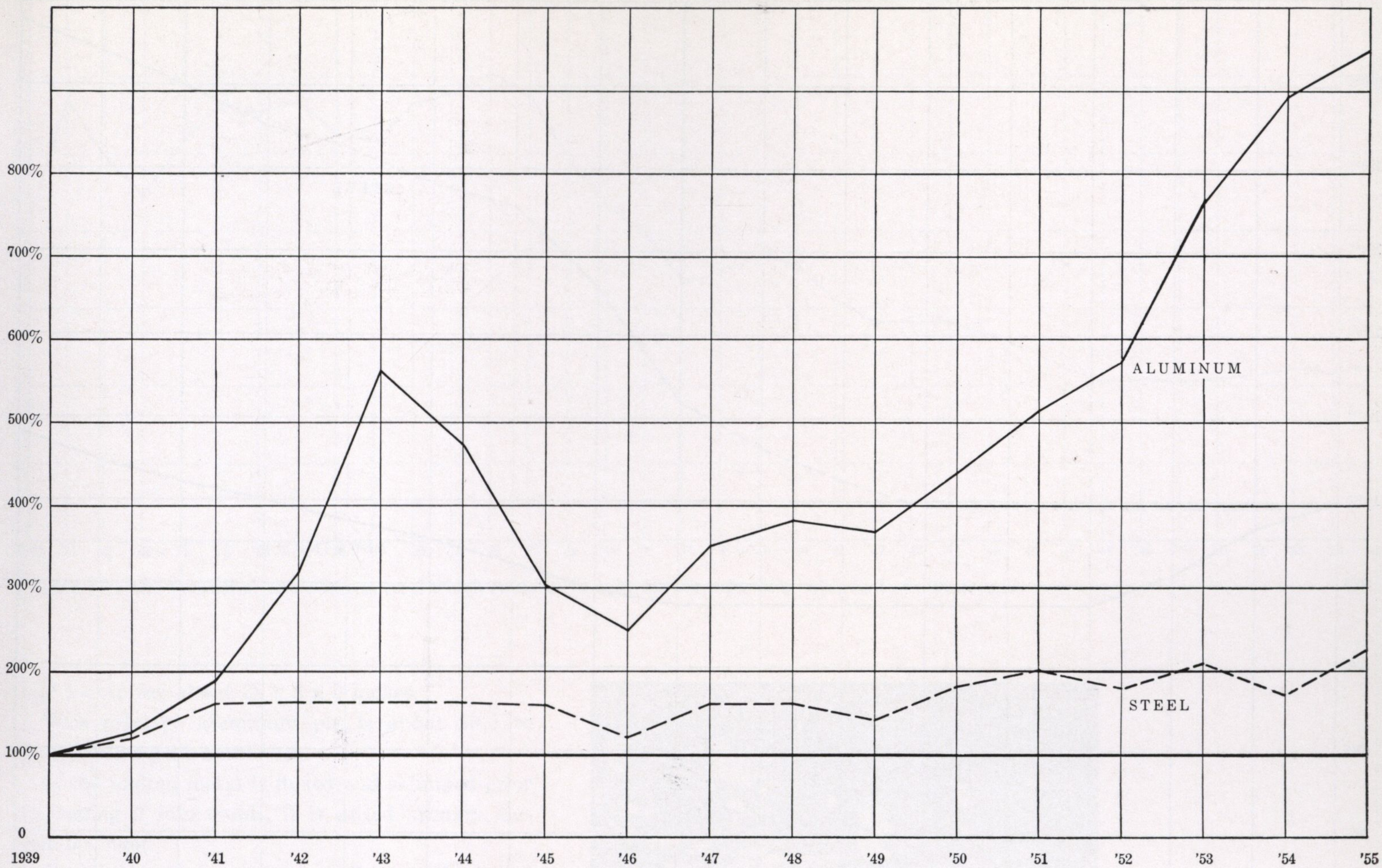


Figure 1-3: Comparison of aluminum and steel production.

The dried ore is ground to a powder and fed into a mixer together with soda ash, crushed lime and hot water in the proper proportions, the soda ash and crushed lime thereby forming caustic soda. The mixture is then pumped into large digesting tanks into which steam is admitted under high pressure to accelerate the reaction. Motor driven agitators bring all materials into intimate contact; the alumina is dissolved by the caustic soda, and then is converted to sodium aluminate; while the other impurities either form insoluble substances or are unaffected by the caustic solution.

The sodium aluminate solution is then passed through pressure reducing tanks and pumped into filter presses where it runs through heavy cotton cloth while the solid impurities, called "red mud" for its red color, are filtered out and then washed off the cloth by jets of water. In some newer plants the red mud is separated from the solution by gravity settling and only the last traces are removed in filter presses.

Next, the solution is pumped into precipitators. In these tanks the sodium aluminate is mixed with a "seed charge" of aluminum hydrate from a previous cycle. Continuous agitation with compressed air and cooling gradually cause the seed particles to grow in size. The mixture is then pumped into thickeners which separate the precipitated alumina

In order to utilize lower grade bauxites economically, a combination process was developed which recovers most of the soda and alumina from bauxite with a silica content of as much as 15 percent.

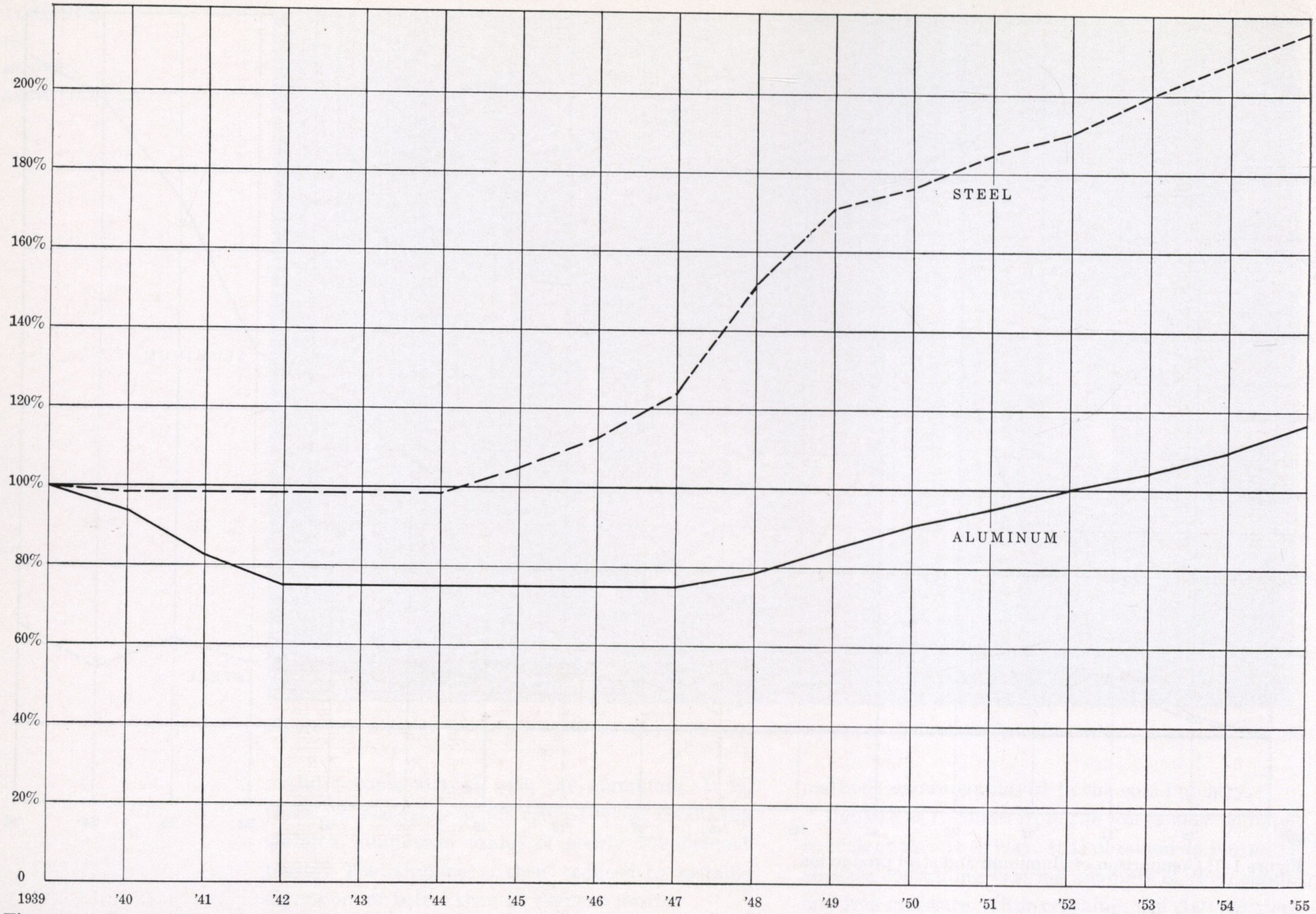


Figure 1-4: Comparative prices of steel and aluminum.

(now aluminum hydrate) from the caustic soda solution which is fed back to the digesters for reuse.

The last step in the refining process is calcining in rotary kilns at 2000°F. This converts the aluminum hydrate to alumina by eliminating the chemically combined water of hydration. After cooling, the alumina is shipped to the reduction plant.

The *reduction process* is basically the same as that developed by Charles Martin Hall in 1886. A carbon-lined vessel or "pot" contains molten cryolite (sodium aluminum fluoride) which dissolves the alumina. An extremely large electric current (d.c.) is passed through the solution, breaking down the alumina into metallic aluminum and oxygen. The aluminum accumulates at the bottom of the reduction pot.

Modern reduction pots (or electrolytic cells) require currents of 100,000 amperes or more, operate at temperatures around 1800° F, and are capable of producing 2000 pounds of aluminum during a 24-hour day. The molten aluminum is siphoned off into large ladles from which it is poured into molds to form pigs weighing 50 pounds each

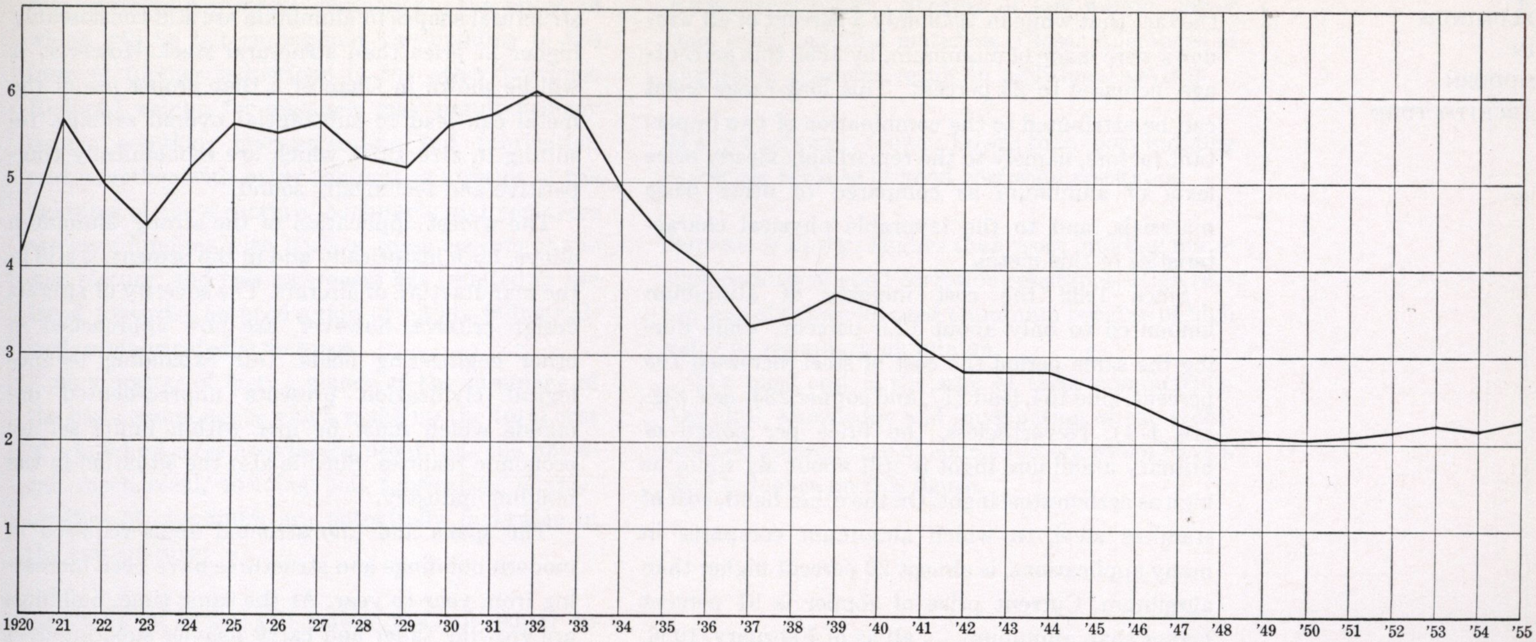


Figure 1-5: The number of cubic feet of steel which could be bought for the price of a cubic foot of aluminum.

and measuring about 28 x 6 x 5 inches.

This primary aluminum pig is about 99.0 to 99.5 percent pure aluminum.

If the molten metal is fluxed and skimmed prior to casting it into molds, it is called primary aluminum ingot.

Both pig and ingot are usually remelted and alloyed (if aluminum alloy is desired), before they are cast into rolling, extrusion or casting ingots (see Figure 3–1).

1.3 ECONOMIC ASPECTS

These techniques of mining and processing have a very great bearing on both the continued availability and on the price structure of aluminum. The fact is that aluminum is the most abundant metallic element found in nature and, potentially, it is twice as plentiful as iron. An increasing share of the demand for metals for various products is being satisfied by steadily growing aluminum production.

As a matter of fact, aluminum production in the U. S. increased more than tenfold between 1939 and 1956, while steel production barely doubled (see

Figure 1-6: Aluminum billets, shown at the left, and pigs, at right, are moved easily by lift trucks.

Figure 1–3). One of the important aspects of the rapidly growing aluminum capacity is the great variety of mill products which are now available. During World War II, about 80 percent of the total output went into military aircraft production. One of the largest users of aluminum is the construction industry. About 23 percent of all aluminum produced in 1955 found its way into the construction industry. The increasing acceptance and use of aluminum in this field is illustrated, for instance, by

the fact that while in 1949 only 5 percent of all windows were made of aluminum, by 1953 this percentage increased to 25 percent. This long-range trend can be attributed to the combination of two important factors, namely to the remarkably steady price level of aluminum as compared to other basic materials, and to the favorable physical characteristics of this metal.

Since 1939 the cost increase of aluminum amounted to only about 12.5 percent, while during the same period the cost of steel increased 103 percent, zinc 154, lead 217, and copper 284. (see Figure 1–4). Nevertheless, the price per pound of primary aluminum ingot is still about six times as high as carbon steel ingot. On the other hand, cost of stainless steel, to which aluminum compares in many applications, is almost 20 percent higher than aluminum. Current price of copper is 91 percent higher than aluminum. . . all as of February, 1956.

Because of its low density, aluminum may very well be compared with other metals on an equal volume basis (see Figure 1-5). On this basis, the price of aluminum, at the present time, is the cheapest of all non-ferrous metals.

The price picture of aluminum is the result of the high technological level of the industry itself. Capital charges are about 10 times as high as in steel production, while labor costs represent only 10–12 percent of the cost of aluminum ingot against 17–20 percent of steel ingot*. The price of aluminum is, therefore, not as much affected by the general tendency of increasing labor costs as is the price of steel.

On the other hand the production facilities of the aluminum industry are undergoing an increasing degree of mechanization, and techniques are continually improving.

Another factor to be considered is the inherently high scrap value of aluminum. The reason for this is that the price of ingot made from scrap (secondary aluminum) need not include the cost of electric energy, which results in a significant cost saving.

Nevertheless, it must be borne in mind that structural shapes in aluminum are still considerably higher in price than structural steel. However, it will be shown in Chapter 5 that proper use of the metal can lead to substantial overall savings, resulting in structures which are economically competitive and technically sound.

The widest application of the strong aluminum alloys, both historically and in the present, is still in the manufacture of aircraft. The severity of aircraft design criteria, however, are now approached in other engineering fields. Our expanding technological civilization presents unprecedented demands which must be met within limits set by economic realities. Such is also the situation in the building industry.

The spans and unobstructed areas required in modern buildings and structures have been increasing from year to year. At the same time, buildings are growing taller and carry heavier superimposed loads. Structures are erected in locations where they are subjected to the most severe types of exposure to extremes of temperature, seismic shocks and winds. Buildings are constructed in areas where in previous times subsurface conditions would have made construction economically, if not technically, impossible. In addition to this, both in civilian and military applications, the speedy erection, transportation (sometimes by air) and quick and easy dismantling of buildings becomes increasingly important.

Engineers, architects and the industry rose to this challenge by devising methods which permitted the fulfillment of these requirements, and new techniques were devised to achieve these aims.

Yet, the struggle to meet the increasing technological demands, and still keep construction costs at an acceptable level, is not always a successful one. The forward-looking designer is continuously in search of new materials and methods which will make the achievement of these aims possible. In a number of instances, savings obtained in one cost component will result in an increase of others. Reduction of field labor costs is often achieved only by increasing the cost of such items as fabrication and transportation.

On the other hand, it is also possible to obtain

*Source: COMPETITION BETWEEN STEEL AND ALUMINUM by United Nations Economic and Social Council—Economic Commission for Europe, Steel Committee, Geneva, Switzerland, February 12, 1954, p. 73.

cost savings in a single component, the effect of which will be felt throughout the building in the form of further reductions in the other portions. Reduced weight, for instance, may simultaneously reduce erection, transportation and fabrication cost, together with other savings, as a result of the lightness of the structure. Architects and engineers are very familiar with both of these aspects of the cost picture; and this awareness has resulted in the trend towards the production of highly industrialized, prefabricated structures.

As a matter of fact, a glance at the summary of the basic components which make up the total cost of a building gives convincing proof that the physical, mechanical, forming and fabricating characteristics of aluminum are potentially favorable in the cost picture:

COST OF MATERIAL: Lower than or equal to stainless steel, on volume basis lowest of non-ferrous metals, higher than structural steel, but potential weight reductions may result in equal or lower cost.

FABRICATION COST: Equal and in many instances lower than that of steel, lower than stainless.

TRANSPORTING AND HANDLING COST: Because of low weight, considerably lower than that of most other building materials.

ERECTION COST: Because of low weight, lower than other building materials. Closer tolerances of aluminum products result in additional savings.

MAINTENANCE COST: Lower than most building materials because of good corrosion resistance.

REUSE VALUE: Higher than most building materials because of good corrosion resistance. High percentage of return on used aluminum because of high value of secondary aluminum.

The total cost is the sum of these components. The skill, knowledge and imagination of the architect and engineer are of course factors which have a vital influence on this figure.

BIBLIOGRAPHY

THE ABC'S OF ALUMINUM by Reynolds Metals Co., 1950

HOW ALUMINUM IS MADE by The Aluminum Association, New York, February 1954.

THE GROWING RESERVES OF ALUMINUM ORE by I. Lipkowitz—Modern Metals 9, January 1954—pp. 42-45.

GLOBAL ALUMINUM by I. Lipkowitz—Modern Metals 10, May 1954—pp. 35-40.

ALUMINUM—WHAT WILL WE DO WITH IT ALL? by D. P. Reynolds—The Iron Age, April 8, 1954.

COMPETITION BETWEEN STEEL AND ALUMINUM by United Nations Economic and Social Council, Economic Commission for Europe—Steel Committee ,Geneva, February 1954.

CHAPTER 2: PHYSICAL AND MECHANICAL PROPERTIES

2.1 THE ALLOY DESIGNATION SYSTEM

A large and useful number of aluminum alloys are currently available. The Aluminum Association (AA) has devised a designation system for wrought alloys. However, for cast alloys, a system of arbitrary numbers is used.

Familiarity with the designation system will facilitate work with aluminum.

In addition to the AA number, the old commercial designations, the A.S.T.M. (American Society for Testing Materials) numbers, and the S.A.E. (Society of Automotive Engineers) numbers are sometimes referred to in technical literature. These, together with Federal, Military, AMS and ASTM Specifications, and certain foreign designations and specifications are listed in the form of conversion tables in the Appendix.

The Aluminum Association Alloy Designation System for Wrought Aluminum:

Wrought aluminum and wrought aluminum alloys are designated by a four-digit index system. The first digit of the designation serves to indicate alloy groups. The last two digits identify the aluminum alloy or indicate the aluminum purity. The second digit indicates modifications of the original alloy or impurity limits.

Aluminum and Aluminum Alloy Groups:

In the four-digit index system the first digit indicates the alloy group as shown in Table 2-1. Thus 1xxx indicates aluminum of 99.00% minimum and greater, 2xxx indicates an aluminum alloy in which copper is the major alloying element, and 3xxx an aluminum alloy with manganese as the major alloying element, etc. Although most aluminum alloys contain several alloying elements, only one group—6xxx for alloys with magnesium and silicon as major alloying elements—designates more than one alloying element.

Aluminum: In the 1xxx group for aluminum of 99.00% minimum and greater, the last two of the four digits in the designation indicate the minimum aluminum percentage. These digits are the same as the two digits to the right of the decimal point in the minimum aluminum percentage when it is expressed to the nearest 0.01%.

The second digit in the designation indicates modifications in impurity limits. If the second digit in the designation is zero, it indicates that there is no special control on individual impurities; while integers 1 through 9, which are assigned consecutively as needed, indicate special control of one or more individual impurities. Thus 1030 indicates 99.30% minimum aluminum without special control on individual impurities and 1130, 1230 and the like indicate the same purity with special control on one or more impurities. Likewise 1075, 1175, 1275 and so on indicate 99.75% minimum aluminum; and 1097, 1197, 1297 indicate 99.97%.

Aluminum Alloys: In the 2xxx through 8xxx alloy groups the last two of the four digits in the designation have no special significance but serve only to identify the different alloys in the group. Generally these digits are the same as those formerly used to designate the same alloy. Thus 2014 was formerly 14S, 3003 was 3S, and 7075 was 75S. For

new alloys these last two digits are assigned consecutively beginning with xx01.

The second digit in the alloy designation indicates alloy modifications. If the second digit in the designation is zero, it indicates the original alloy; while integers 1 through 9, which are assigned consecutively, indicate alloy modifications. In the former system, letters were used to designate alloy modifications. These were assigned consecutively beginning with A. Thus 17S is now 2017 and A17S is 2117; 18S is 2018 and B18S is 2218.

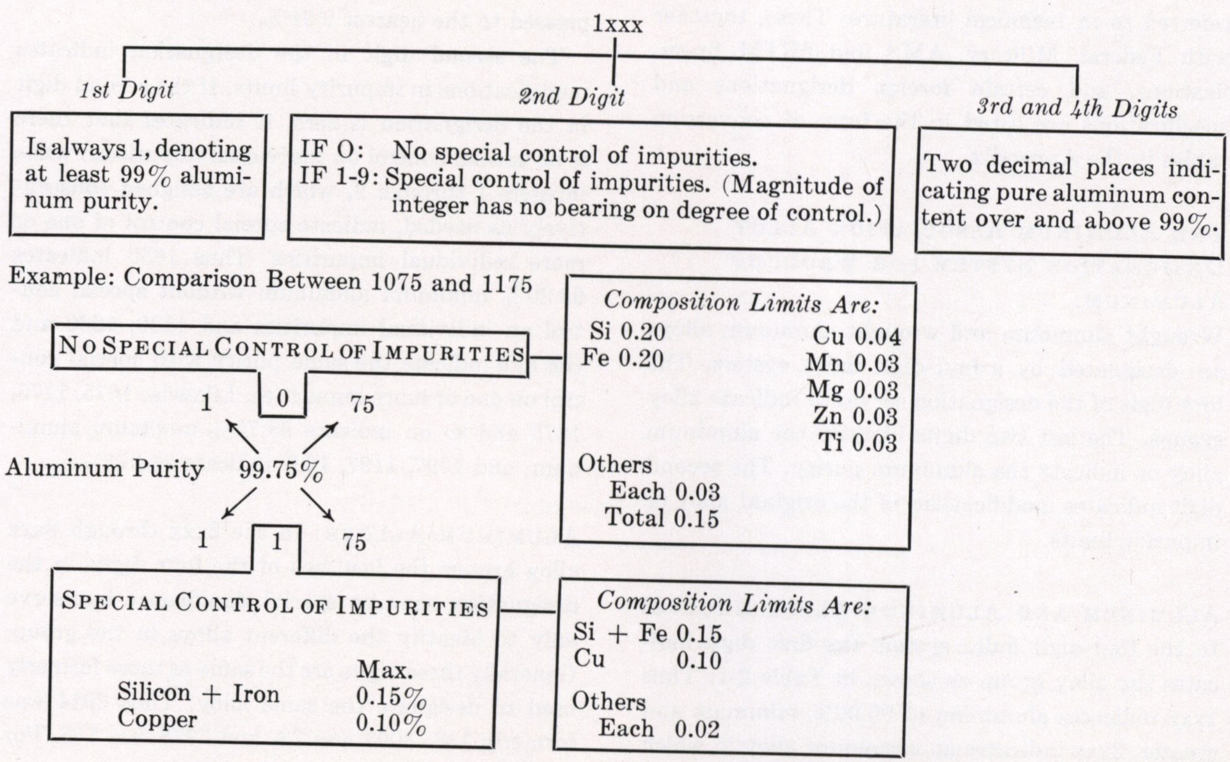
EXPERIMENTAL ALLOYS: Experimental alloys are also designated in accordance with this system but they are indicated by the prefix X. The prefix is dropped when the alloy becomes standard. During development, and before they are designated as experimental, new alloys are identified by serial numbers assigned by their originators. Use of the serial number is discontinued when the X number is assigned.

TEMPER DESIGNATIONS: The temper designation system in effect since December 31, 1947, is being continued without change. The temper designation follows the alloy designation and is separated from it by a dash. Thus 3S-0 is now 3003-0, Alclad 24S-T81 is Alclad 2024-T81, 75S-T6 is 7075-T6.

TABLE 2-1: DESIGNATIONS FOR ALLOY GROUPS

		AA Number
Aluminum	99.00% minimum and greater	1xxx
	Major Alloying Element	
Aluminum Alloys grouped by major Alloying Elements	Copper	2xxx
	Manganese	3xxx
	Silicon	4xxx
	Magnesium	5xxx
	Magnesium and Silicon	6xxx
	Zinc	7xxx
	Other element	8xxx
Unused Series		9xxx

SCHEMATIC REPRESENTATION OF THE AA NUMBERS FOR *HIGH PURITY WROUGHT ALUMINUM*



SCHEMATIC REPRESENTATION OF THE AA NUMBERS FOR *WROUGHT ALUMINUM ALLOYS*

X X X X

1st Digit	2nd Digit	3rd and 4th Digits
Major alloying element as follows:	*Modification of alloy*	*Arbitrary Number to identify alloy within the series*
2 xxx—Copper 3 xxx—Manganese 4 xxx—Silicon 5 xxx—Magnesium 6 xxx—Magnesium & Silicon 7 xxx—Zinc 8 xxx—Other element 9 xxx—Unused series	x0xx—original alloy x1xx x2xx x3xx x4xx x5xx x6xx x7xx x8xx x9xx — Alloy Modifications	

The meaning of the second digit may be further clarified by the following example:

Alloy 2017 contains, besides other minor elements, 4% copper, 0.5% manganese, and .5% magnesium. The second digit is zero and therefore indicates that 2017 is the original alloy. The alloy 2117 containing 2.5% copper and .3% magnesium is the first modification. Alloy 2217 will represent the second modification of the basic alloy 2017.

In the designations of *Clad Products* (see Sections 2.2 and 3.6) the AA number is preceded by the word *Alclad.* The cladding alloy itself is not identified. (Alclad 2024 is clad with alloy 1230, for instance, while Alclad 7075 is clad with alloy 7072.)

Mill products used *for a specific purpose*, such as roofing sheet, utility sheet, brazing sheet and the like continue to be designated by these commodity names. The designation EC for elecrtical conductor grade aluminum with 99.45% minimum purity has become firmly established in the electrical industry. Moreover, the use of this alloy is based on guaranteed electrical conductivity, but not on a guaranteed chemical composition.

Temper Designations are separated from the alloy by a dash. The letter "H" is used for non-heat-treatable and the letter "T" for heat-treatable alloys. Note that some temper designations apply only to wrought products, others to cast products, but most apply to both. Additional digits to the right indicate variations in the basic treatment.

TABLE 2-2: TEMPER DESIGNATIONS

–F	As fabricated.
–O	Annealed and recrystallized (wrought only).
–H	Strain hardened (wrought only).
	–H1, plus one or more digits.* Strain hardened only.
	–H2, plus one or more digits.* Strain hardened, then partially annealed.
	–H3, plus one or more digits.* Strain hardened, then stabilized.
–W	Solution heat treated—unstable temper.
–T	Treated to produce stable tempers other than –F, –O or –H.
	–T2 Annealed (cast only).
	–T3 Solution heat treated, then cold worked.
	–T4 Solution heat treated and naturally aged to a substantially stable condition.

* Second digit indicates final degree of strain hardening, i.e. 2 is ¼ hard 4 is ½ hard, 6 is ¾ hard, 8 is full hard.

TABLE 2-2: TEMPER DESIGNATIONS

–T5	Artificially aged only.
–T6	Solution heat treated, then artificially aged.
–T7	Solution heat treated, then stabilized.
–T8	Solution heat treated, cold worked, then artificially aged.
–T9	Solution heat treated, artificially aged, then cold worked.
–T10	Artificially aged, then cold worked.

Temper designations in effect prior to December 31, 1947 may sometimes be found in literature. For the purpose of indentification, conversion tables are provided in the Appendix.

2.2 METALLURGICAL ASPECTS

In high purity form, aluminum is extremely soft and ductile. Most commercial uses, however, require greater strength than pure aluminum affords. This is achieved in aluminum first by the addition of other elements to produce various alloys (see Table 2-3), which singly or in combination impart strength to the metal. Further strengthening is possible by means which classify the alloys roughly into two categories, non-heat-treatable and heat-treatable.

NON-HEAT-TREATABLE ALLOYS: The initial strength of alloys in this group depends upon the hardening effect of elements such as manganese, silicon, iron and magnesium, singly or in various combinations. The non-heat-treatable alloys are usually designated, therefore, in the 1000, 3000, 4000, or 5000 series. Since these alloys are work hardenable, further strengthening is made possible by various degrees of cold working, denoted by the "H" series of tempers. Alloys containing appreciable amounts of magnesium when supplied in strain-hardened tempers are usually given a final elevated temperature treatment, called "stabilizing," to insure stability of properties.

HEAT-TREATABLE ALLOYS: Aluminum alloys in this group derive their great strength from such alloying elements as copper, magnesium, zinc and silicon. Since these elements singly or in various combinations show increasing solid solubility in aluminum with increasing temperature, it is possible to subject these alloys to thermal treatments which will impart pronounced strengthening.

The first step, called heat treatment or solution heat treatment, is an elevated temperature process designed to put the soluble constituents in solid solution. This is followed by rapid quenching, usually in water, which "freezes" the metallurgical structure and for a short time renders the alloy very workable. It is at this stage that some fabricators retain this more workable structure by storing the alloys at below-freezing temperatures until they are ready to form them. At room or elevated temperatures most alloys are not stable after quenching, however, and precipitation of the constituents from the super-saturated solution begins. After a period of several days at room temperature, termed aging or room temperature precipitation, the alloy is considerably stronger. Many alloys approach a stable condition at room temperature, but some alloys, particularly those containing magnesium and silicon or magnesium and zinc, continue to age harden for long periods of time at room temperature.

By heating for a controlled time at slightly elevated temperatures, even further strengthening is possible and properties are stabilized. This process is called artificial aging or precipitation hardening. By the proper combination of solution heat treatment, quenching, cold working and artificial aging, the highest strengths are obtained.

CLAD ALLOYS: The heat-treatable alloys in which copper or zinc are major alloying constituents, are less resistant to corrosive attack than the majority of non-heat-treatable alloys. To increase the corrosion resistance of these alloys in sheet and plate form they are often clad with high purity aluminum, a low magnesium-silicon alloy, or an alloy containing 1% zinc. The cladding, usually from 2½ to 5% of the total thickness on each side, not only protects the composite due to its own inherently excellent corrosion resistance but also exerts a galvanic effect which further protects the

TABLE 2-3: CHEMICAL COMPOSITIONS FOR WROUGHT AND CAST ALUMINUM ALLOYS

(Values in Percent Maximum Unless Shown as a Range)

	0	1	2	3	4	5	6	7	8	9	10		11
	ALLOY	SILICON	IRON	COPPER	MANGANESE	MAGNESIUM	CHROMIUM	NICKEL	ZINC	TITANIUM	OTHERS each	OTHERS total	ALUMINUM min
WROUGHT ALLOYS	1100	1.00 Si + Fe		0.20	0.05	—	—	—	0.10	—	0.05	0.15	99.00
	2011*	0.40	0.70	5.00–6.00	—	—	—	—	0.30	—	0.05	0.15	Remainder
	2014	0.50–1.20	1.00	3.90–5.00	0.40–1.20	0.20–0.80	0.10	—	0.25	0.15	0.05	0.15	Remainder
	2017	0.80	1.00	3.50–4.50	0.40–1.00	0.20–0.80	0.10	—	0.25	—	0.05	0.15	Remainder
	2024	0.50	0 50	3.80–4.90	0.30–0.90	1.20–1.80	0.10	—	0.25	—	0.05	0.15	Remainder
	3003	0.60	0.70	0.20	1.00–1.50		—	—	0.10	—	0.05	0.15	Remainder
	3004	0.30	0.70	0.20	1.00–1.50	0.80–1.30	—	—	0.10	—	0.05	0.15	Remainder
	4043	4.50–6.00	0.80	0.30	0.05	0.05	—	—	0.10	0 20	0.05	0.15	Remainder
	5005	0 40	0.70	0.20	0.20	0.50–1.10	0.10	—	0.25	—	0.05	0.15	Remainder
	5050	0.40	0.70	0.20	0.10	1.00–1.80	0.10	—	0.25	—	0.05	0.15	Remainder
	5052	0.45 Si + Fe		0.10	0.10	2.20–2.80	0.15–0.35	—	0.20	—	0.05	0.15	Remainder
	5154	0.45 Si + Fe		0.10	0.10	3.10–3.90	0.15–0.35	—	0.20	0.20	0.05	0.15	Remainder
	6053	45%–65% of magnesium	0.35	0.10	—	1.10–1.40	0.15–0.35	—	0.10	—	0.05	0.15	Remainder
	6061	0.40–0.80	0.70	0.15–0.40	0.15	0.80–1.20	0.15–0.35	—	0.25	0.15	0.05	0.15	Remainder
	6062	0.40–0.80	0.70	0.15–0.40	0.15	0.80–1.20	0.04–0.14	—	0.25	0.15	0.05	0.15	Remainder
	6063	0.20–0.60	0.35	0.10	0.10	0.45–0.90	0.10	—	0.10	0.10	0.05	0.15	Remainder
	7075	0.50	0.70	1.20–2.00	0.30	2.10–2.90	0.18–0.40	—	5.10–6.10	0.20	0.05	0.15	Remainder
CAST ALLOYS	43	4.50–6.00	0.60	0.10	0.10	0.05	—	—	0.10	0.20	0.05	0.15	Remainder
	214	0.30	0.30	0.10	0.30	3.70–4.50	—	—	0.10	0.20	0.05	0.15	Remainder
	A214	0.30	0.30	0.10	0.30	3.50–4.50	—	—	1.40–2.20	0.20	0.05	0.15	Remainder
	B214	1.40–2.20	0.30(1)	0.10(1)	0 30(1)	3.50–4.50	0.20	—	0.10	0.20	0.05	0.15	Remainder
	F214	0.30–0.70	0.30	0.10	0.30	3.50–4.50	—	—	0.10	0.20	0.05	0.15	Remainder
	L214	0.30	0.80	0.12	0.40–0.60	3.50–4.50	—	—	0.10	—	0.05	0.15	Remainder
	356	6.50–7.50	0.40	0.20	0.10	0.20–0.40	—	—	0.10	0.20	0.05	0.15	Remainder

* Also contains 0.20–0.60% each of lead and bismuth.
(1) If the copper content plus the iron content exceeds 0.50%, the manganese content will be at least 0.30%.

core material against corrosive attack.

Special composites such as clad non-heat-treatable alloys may be obtained. These have applications for extra corrosion resistance, for brazing purposes, or for special surface finishes. Some alloys in wire and tubular form are clad for similar reasons and extrusions also have been clad on an experimental basis.

ANNEALING CHARACTERISTICS: All wrought aluminum alloys are available in annealed form. In addition, it may be desirable to anneal an alloy

from any other initial temper, after working, or between successive stages of working such as in deep drawing.

EFFECTS OF ALLOYING ELEMENTS.
WROUGHT ALLOYS:

1000 Series: Aluminum of 99% or higher purity has many applications, especially in the electrical and chemical fields. These alloys are characterized by excellent corrosion resistance, high thermal and electrical conductivity, low mechanical properties and excellent workability. Moderate increases in strength may be obtained by strain hardening. Iron and silicon are the major impurities.

2000 Series: Copper is the principal alloying element in this group. These alloys require solution heat treatment to obtain optimum properties; in the heat-treated condition mechanical properties are similar to, and sometimes exceed, those of mild steel. In some instances artificial aging is employed to further increase the mechanical properties. This treatment materially increases yield strength, with attendant loss in elongation; its effect on tensile (ultimate) strength is not as great. The alloys in the 2000 series do not have as good corrosion resistance as most other aluminum alloys and under certain conditions they may be subject to intergranular attack. Therefore, these alloys in the form of sheet are usually clad with high-purity alloy or a magnesium-silicon alloy of the 6000 series which provides galvanic protection to the core material and thus greatly increases resistance to corrosion. Alloy 2024 is perhaps the best known and most widely used aircraft alloy.

3000 Series: Manganese is the major alloying element of alloys in this group, which are generally non-heat-treatable. Because only a limited percentage of manganese, up to about 1.5%, can be effectively added to aluminum, it is used as a major element in only a few instances. One of these, however, is the popular 3003, which is widely used as a general-purpose alloy for moderate-strength applications requiring good workability.

4000 Series: Major alloying element of this group is silicon, which can be added in sufficient quantities to cause substantial lowering of the melting point without producing brittleness in the resulting alloys. For these reasons aluminum-silicon alloys are used in welding wire and as brazing alloys where a lower melting point than that of the parent metal is required. Most alloys in this series are non-heat-treatable, but when used in welding heat-treatable alloys they will pick up some of the alloying constituents of the latter and so respond to heat treatment to a limited extent. The alloys containing appreciable amounts of silicon become dark grey when anodic oxide finishes are applied, and hence are desired for certain architectural applications.

5000 Series: Magnesium is one of the most effective and widely used alloying elements for aluminum. When employed as the major alloying element or with manganese, the result is a moderate-to-high-strength non-heat-treatable alloy. Magnesium is considerably more effective than manganese as a hardener, about 0.8% magnesium being equal to 1.25% manganese; and it can be added in considerably greater quantities. These alloys have especially good resistance to corrosion in marine atmospheres and sea water. Prominent in this series are 5052, having 2.5% magnesium, and 5050, in which the magnesium content is 1.4%.

6000 Series: Alloys in this group contain silicon and magnesium in approximate proportions required to form magnesium silicide, thus making them capable of being heat treated. Major alloy in this series is 6061, one of the most versatile of the heat-treatable alloys. Though less strong than most alloys of the 2000 or 7000 series, the magnesium-silicon (or magnesium silicide) series possesses good formability and corrosion resistance, with medium strength. Alloys in this heat-treatable group may be formed in the T4 temper (solution heat treated but not artificially aged) and then reach full T6 properties by artificial aging.

7000 Series: Zinc is the major alloying element in this group, and in combination with a smaller percentage of magnesium results in heat-treatable alloys of very high strength. Usually other elements such as copper and chromium are also added in small quantities. Outstanding member of this group is 7075, which is among the highest strength alloys available. It is frequently used in air-frame struc-

tures and for other highly stressed parts.

EFFECTS OF ALLOYING ELEMENTS.

CAST ALLOYS:

Copper: (With or without other alloying elements). Increases strength. Castability satisfactory, especially in the presence of other constituents; castability and corrosion resistance inferior to the aluminum-silicon group. Heat-treatable. Low ductility if not heat treated. Good machining qualities.

Silicon: (With or without other alloying elements). Excellent castability for all types of castings. High corrosion resistance. Without other alloying elements, silicon alloys are non-heat-treatable resulting in moderate strengths. With other alloying elements, these alloys are heat-treatable and develop relatively high strengths after heat treatment, but copper and magnesium should be kept at a minimum to retain ductility and castability. High silicon percentage results in low coefficient of linear expansion, relatively good ductility, poor machinability.

Magnesium: Excellent corrosion resistance, high strength, good machinability and finishing characteristics. Heat-treatable if alloy has high magnesium percentage. Castability and weldability fair.

Zinc: (With small amounts of copper). High mechanical properties (without heat treatment). Good machinability.

Nickel: (Minor alloying element only). Increases strength at elevated temperatures, usually with other alloying elements.

Iron: Sometimes used to reduce shrinkage. High iron in alloys containing more than 5% silicon results in coarse structure. About 0.8% iron in alloys containing more than 8% silicon tends to eliminate welding of dies in die casting. The iron content in most aluminum casting alloys must be closely controlled if the maximum mechanical properties are to be obtained.

2.3 PHYSICAL, MECHANICAL AND FABRICATING DATA

The essential physical, mechanical and fabricating characteristics of aluminum alloys are presented in Tables 2-4 and 2-5, with supplementary information in Figure 2-1 and Table 2-6. For more extensive treatment of these topics, the reader is referred to the sources listed in the bibliography. The alloys listed are restricted to those which are commonly used in the building industry. All the pertinent information on those alloys is made available in only two tables, Table 2-4 (for wrought alloys) and Table 2-5 (for cast alloys), clarifying the relationship between the various characteristics of the material. This type of presentation is more useful than a more extensive coverage in a larger number of detailed tables.

The designer usually selects and specifies an alloy because of one or several desirable qualities required for his specific purpose. It is essential, however, to be aware of other characteristics which may have only a secondary bearing on the selection. An ideal choice of an alloy should be a selection which takes into account all or at least a large number of properties. The compact "horizontal" presentation of the data in Tables 2-4 and 2-5 will make it possible to obtain at a glance all the relevant information which the designer should be aware of when choosing the material. For instance, the designer may desire to specify an alloy for a product which will require good weathering characteristics. As a first guide in his selection, he should consult Table 2-9 which gives a list of suggested alloys employed for various building products. After that, the section on corrosion and the data included in Table 2-4 or 2-5 will help him choose one or two suitable alloys. At the same time Table 2-4 or 2-5, (depending on whether the alloy is wrought or cast) will call his attention to a number of other properties which should be considered. This table should also (and probably in the first place) call his attention to the fabricating characteristics of the alloy. For further information on this topic, he may want to refer to Chapter 3, but Table 2-4 or 2-5 will indicate numerous other qualities which may improve the product, such as strength, hardness, etc.

The implications of the data covered in these tables are treated in greater detail in other parts of the book and therefore, in a sense, this section represents a brief summary of all relevant data. Succeeding sections will refer often to these data.

TABLE 2-4: TYPICAL PHYSICAL, MECHANICAL, FABRICATING PROPERTIES OF WROUGHT ALUMINUM ALLOYS

NON-HEAT-TREATABLE (COMMON) ALLOYS

AA ALLOY NUMBER	TEMPER DESIGNATION	PHYSICAL CHARACTERISTICS — WEIGHT: SPECIFIC GRAVITY	WEIGHT: DENSITY ω lbs/in³	WEIGHT: DENSITY ω lbs/ft.³	THERMAL: APPROXIMATE MELTING RANGE Degrees F	THERMAL: COEFFICIENT OF EXPANSION PER °F ×10⁻⁶ (68°–212°F)	THERMAL: CONDUCTIVITY AT 77° F btu/in./ft²/°F/hr	ELECTRICAL: CONDUCTIVITY AT 68°F, % OF INTERNATIONAL ANNEALED COPPER STANDARD — EQUAL VOLUME	ELECTRICAL: CONDUCTIVITY — EQUAL WEIGHT	ELECTRICAL: RESISTIVITY AT 68°F — μ ohms/cm³	ELECTRICAL: RESISTIVITY — ohms/mil-ft	MECHANICAL CHARACTERISTICS — TENSION: STRENGTH psi — f_u ULTIMATE	TENSION: STRENGTH psi — f_y YIELD	TENSION: ELONGATION IN 2 INCHES % — 1/16″ THICK SPECIMEN	TENSION: ELONGATION — 1/2″ DIAM SPECIMEN	TENSION: f_u/f_y ULTIMATE TO YIELD STRENGTH RATIO	TENSION: STRENGTH-WEIGHT RATIO — ULTIMATE $f_u/\omega \times 10^4$ in.	TENSION: STRENGTH-WEIGHT RATIO — YIELD $f_y/\omega \times 10^4$ in.	COMPRESSION: YIELD STRENGTH psi	COMPRESSION: SHORT COLUMN STRENGTH COEFF. CRITICAL STRESS $f_c = a - bk(L/r)$; $k(L/r) < c$ — a	COMPRESSION: b	COMPRESSION: c	SHEAR: ULTIMATE STRENGTH psi
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	-O						1540	59	194	2.9	17	13,000	5,000	35	45	2.60	13.27	5.10	5,000				9,000
	-H12											16,000	15,000	12	25	1.07	16.33	15.31	15,000				10,000
1100	-H14	2.71	0.098	169	1190–	13.10	1520	58	189	3.0	18	18,000	17,000	9	20	1.06	18.37	17.35	17,000	n.a.	n.a.	n.a.	11,000
	-H16				1215							21,000	20,000	6	17	1.05	21.43	20.41	20,000				12,000
	-H18						1510	57	187			24,000	22,000	5	15	1.09	24.49	22.45	22,000				13,000
	-O						1340	50	163	3.4	21	16,000	6,000	30	40	2.67	16.16	6.06	6,000	6,200	18	220	11,000
	-H12						1130	42	137	4.1	25	19,000	18,000	10	20	1.06	19.19	18.18	18,000	18,400	95	126	12,000
3003	-H14	2.73	0.099	170	1190–	12.90	1100	41	134	4.2	25	22,000	21,000	8	16	1.05	22.22	21.21	21,000	20,800	115	120	14,000
	-H16				1210		1085	40	132	4.3	26	26,000	25,000	5	14	1.04	26.26	25.25	25,000	29,400	145	108	15,000
	-H18						1070		130			29,000	27,000	4	10	1.07	29.29	27.27	27,000	29,400	193	101	16,000
	-O											26,000	10,000	20	25	2.60	26.53	10.20	10,000				16,000
	-H32											31,000	25,000	10	17	1.24	31.63	25.51	25,000				17,000
3004	-H34	2.72	0.098	170	1165–	13.30	1130	42	137	4.1	25	35,000	29,000	9	12	1.21	35.71	29.59	29,000	n.a.	n.a.	n.a.	18,000
	-H36				1205							38,000	33,000	5	9	1.15	38.78	33.67	33,000				20,000
	-H38											41,000	36,000	5	6	1.14	41.84	36.73	36,000				21,000
	-O											18,000	6,000	30		3.00	18.37	6.12	6,000				11,000
	-H12											20,000	9,000	10		2.22	20.41	19.39	19,000				14,000
	-H14											23,000	22,000	6		1.05	23.47	22.45	22,000				14,000
	-H16											26,000	25,000	5		1.04	26.53	25.51	25,000				15,000
5005	-H18	2.70	0.098	169	1170–	13.20	1390	52	172	3.3	20	29,000	28,000	4	n.a.	1.04	29.59	28.57	28,000	n.a.	n.a.	n.a.	16,000
	-H32				1205							20,000	17,000	11		1.18	20.41	17.35	17,000				14,000
	-H34											23,000	20,000	8		1.15	23.47	20.41	20,000				14,000
	-H36											26,000	24,000	6		1.08	26.53	24.49	24,000				15,000
	-H38											29,000	27,000	5		1.07	29.59	27.55	27,000				16,000
	-O											21,000	8,000	24		2.63	21.65	8.25	8,000				15,000
	-H32											25,000	21,000	9		1.19	25.77	21.65	21,000				17,000
5050	-H34	2.69	0.097	168	1160–	13.20	1340	50	165	3.4	21	28,000	24,000	8	n.a.	1.17	28.87	24.74	24,000	n.a.	n.a.	n.a.	18,000
	-H36				1205							30,000	26,000	7		1.15	30.93	26.80	26,000				19,000
	-H38											32,000	29,000	6		1.10	32.99	29.90	29,000				20,000

MECHANICAL CHARACTERISTICS					MILL PRODUCTS AVAILABILITY												FORMING AND FABRICATING										CORROSION RESISTANCE					
BEARING							TUBES			SHAPES									WELDING							OUTDOOR ATMOSPHERES					
EDGE DISTANCE = 2.0×RIVET DIA																															
ULTIMATE STRENGTH psi	YIELD STRENGTH psi	ENDURANCE LIMIT psi	MODULUS OF ELASTICITY psi	BRINELL HARDNESS 500 kg load 10 mm ball	SHEET	PLATE	DRAWN	EXTRUDED	PIPE	ROLLED	EXTRUDED	ROD	BAR	WIRE	RIVETS	FORGINGS & FORGING STOCK	FORMING (Sheet only)	MACHINING	RESISTANCE	PRESSURE	GAS	ARC W/FLUX	ARC W/INERT GAS	BRAZING	SOLDERING	RURAL	INDUSTRIAL	MARINE	SEA WATER	AA ALLOY NUMBER	TEMPER DESIGNATION
25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56
23,400	9,000	5,000		23													A	C	C												-O
28,800	27,000	6,000		28													A	C													-H12
32,400	30,600	7,000	10.0×10^6	32	•	•	•	•	•		•	•	•	•	•	•	A	B	A	A	A	A	A	A	A	A+	A	A	A	1100	-H14
37,800	36,000	9,000		38													A	C													-H16
43,200	39,600	9,000		44													B	B	A												-H18
28,800	10,800	7,000		28													A	C	C												-O
34,200	32,400	8,000		35													A	C													-H12
39,600	37,800	9,000	10.0×10^6	40	•	•	•	•	•		•	•	•	•		•	B	C	A	A	A	A	A	A	A	A+	A	A	A	3003	-H14
46,800	45,000	10,000		47													B	C													-H16
52,200	48,600	10,000		55													C	B	A												-H18
46,800	18,000	14,000		45													A	C	C	A	B										-O
55,800	45,000	15,000		32													B	C													-H32
63,000	52,200	15,000	10.0×10^6	63	•	•											B	C	A	n.a.		A	A	B	B	A+	A	A	A	3004	-H34
68,400	59,400	16,000		70													C	C													-H36
73,800	64,800	16,000		77													D	B	A	B	B										-H38
32,400	10,300			28													A	C													-O
36,000	16,200			n.a.													A	C													-H12
41,400	39,600			n.a.													B	C													-H14
46,800	45,000			n.a.													B	C													-H16
52,200	50,400	n.a.	10.0×10^6	n.a.	•	•											C	B	A	n.a.	C	C	A	A	n.a.	A+	A	A	A	5005	-H18
36,000	30,600			36													A	C													-H32
41,400	36,000			41													B	C													-H34
46,800	43,200			46													B	C													-H36
52,200	48,600			51													C	B													-H38
37,800	14,400	12,000		36													A	C	C	A											-O
45,000	37,800	13,000		46													A	C													-H32
50,400	43,200	13,000	10.0×10^6	53	•	•	•					•	•	•			B	C	A	n.a.	A	A	A	B	B	A+	A	A	A	5050	-H34
54,000	46,800	14,000		58													C	C													-H36
57,600	52,200	14,000		65													D	B	A	B											-H38

TABLE 2-4: TYPICAL PROPERTIES OF WROUGHT ALUMINUM ALLOYS (Concluded)

		PHYSICAL CHARACTERISTICS										MECHANICAL CHARACTERISTICS											
		WEIGHT			THERMAL			ELECTRICAL				TENSION							COMPRESSION				SHEAR
			DENSITY ω					CONDUCTIVITY AT 68°F, % OF INTERNATIONAL ANNEALED COPPER STANDARD		RESISTIVITY AT 68°F		STRENGTH psi		ELONGATION IN 2 INCHES %			STRENGTH-WEIGHT RATIO			SHORT COLUMN STRENGTH COEFF. CRITICAL STRESS $f_c = a - bk(L/r)$; $k(L/r) < c$			
AA ALLOY NUMBER	TEMPER DESIGNATION	SPECIFIC GRAVITY	lbs/in.³	lbs/ft³	APPROXIMATE MELTING RANGE Degrees F	COEFFICIENT OF EXPANSION PER °F × 10⁻⁶ (68°–212°F)	CONDUCTIVITY AT 77°F btu/in./ft²/°F/hr	EQUAL VOLUME	EQUAL WEIGHT	μ ohms cm³	ohms mil-ft	f_u ULTIMATE	f_y YIELD	1/8″ THICK SPECIMEN	1/2″ DIAM SPECIMEN	f_u/f_y ULTIMATE TO YIELD STRENGTH RATIO	ULTIMATE $\frac{f_u}{\omega \times 10^4}$ in.	YIELD $\frac{f_y}{\omega \times 10^4}$ in.	YIELD STRENGTH psi	a	b	c	ULTIMATE STRENGTH psi
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
NON-HEAT-TREATABLE (COMMON) ALLOYS																							
	-O											28,000	13,000	25	30	2.15	28.87	13.40	13,000	13,850	62	148	18,000
	-H32											33,000	28,000	12	18	1.18	34.02	28.87	28,000	30,600	204	100	20,000
5052	-H34	2.68	0.097	167	1100–1200	13.20	960	35	116	4.9	30	38,000	31,000	10	14	1.23	39.18	31.96	31,000	35,800	258	92	21,000
	-H36											40,000	35,000	8	10	1.14	41.24	36.08	35,000	39,800	302	85	23,000
	-H38											42,000	37,000	7	8	1.14	43.30	38.14	37,000	42,500	338	84	24,000
	-O											35,000	18,000	27		1.94	36.46	18.75	18,000				18,000
	-H112											35,000	17,000	25		2.19	36.46	16.67	16,000				n.a.
5154	-H32	2.66	0.096	166	1100–1190	13.30	870	32	107	5.3	32	39,000	30,000	15	n.a.	1.30	40.62	31.25	30,000	n.a.	n.a.	n.a.	22,000
	-H34											42,000	33,000	13		1.27	43.75	34.37	33,000				24,000
	-H36											45,000	36,000	12		1.25	46.87	37.50	36,000				26,000
	-H38											48,000	39,000	10		1.23	50.00	40.62	39,000				28,000
HEAT-TREATABLE (STRONG) ALLOYS																							
2011	-T3	2.82	0.102	176	995–1190	12.70	990	36	113	4.8	29	55,000	43,000	n.a.	15	1.28	53.92	42.16	43,000	n.a.	n.a.	n.a.	32,000
	-T8						n.a.	n.a.	n.a.	n.a.	n.a.	59,000	45,000		12	1.31	57.84	44.12	45,000				35,000
2014	-T4	2.80	0.101	175	950–1180	12.80	840	30	95	5.7	35	62,000	42,000	n.a.	20	1.48	61.39	41.58	42,000	50,800	440	77	38,000
	-T6						1070	40	127	4.3	26	70,000	60,000		13	1.17	69.31	59.41	60,000	78,000	840	62	42,000
2017	-T4	2.79	0.101	175	955–1185	13.10	840	30	96	5.7	35	62,000	40,000	n.a.	22	1.55	61.39	39.60	40,000	48,000	405	79	38,000
	-T3						840	30	96	5.7	35	70,000	50,000	18	n.a.	1.40	70.00	50.00	50,000	59,500	560	71	41,000
2024	-T36	2.77	0.100	173	935–1180	12.90	840	30	96	5.7	35	72,000	57,000	13	n.a.	1.26	72.00	57.00	57,000	n.a.	n.a.	n.a.	42,000
	-T4						840	30	96	5.7	35	68,000	47,000	20	19	1.45	68.00	47.00	47,000	59,500	553	71	41,000
6053	-T4	2.69	0.097	167	1075–1205	n.a.	1070	40	n.a.	n.a.	n.a.	33,000	20,000	n.a.	30	1.65	34.02	20.62	20,000	n.a.	n.a.	n.a.	20,000
	-T6											39,000	33,000		20	1.18	40.21	34.02	33,000				24,000
6061	-T4	2.70	0.098	169	1080–1200	13.10	1070	40	132	4.3	26	35,000	21,000	22	25	1.67	35.71	21.43	21,000	23,200	135	115	24,000
	-T6											45,000	40,000	12	17	1.13	45.92	40.82	40,000	49,400	422	78	30,000
6062	-T4	2.70	0.098	169	1100–1205	13.00	1070	40	132	4.3	26	35,000	21,000	n.a.	25	1.67	35.71	21.43	21,000	n.a.	n.a.	n.a.	24,000
	-T6											45,000	40,000	n.a.	17	1.13	45.92	40.82	40,000				30,000
	-T4						n.a.	n.a.	n.a.	n.a.	n.a.	25,000	13,000	22		1.92	25.51	13.27	13,000	n.a.	n.a.	n.a.	n.a.
	-T42						1340	50	165	3.4	21	22,000	13,000	20		1.69	22.45	13.27	13,000	13,850	62	148	14,000
	-T5						1390	53	175	3.3	20	27,000	21,000	12		1.29	27.55	21.43	21,000	26,900	169	106	17,000
6063	-T6	2.70	0.098	169	1140–1205	13.00	1390	53	175	3.3	20	35,000	31,000	12	n.a.	1.13	35.71	31.63	31,000	34,500	245	94	22,000
	-T83											37,000	35,000	9		1.06	37.76	35.71	35,000				22,000
	-T831						n.a.	n.a.	n.a.	n.a.	n.a.	30,000	27,000	10		1.11	30.61	27.55	27,000	n.a.	n.a.	n.a.	18,000
	-T832											42,000	39,000	12		1.08	42.86	39.80	39,000				27,000
7075	-T6	2.80	0.101	175	890–1180	13.10	840	30	95	5.7	35	83,000	73,000	11	11	1.14	82.18	72.28	73,000	76,000	14.3	53	48,000

MECHANICAL CHARACTERISTICS					MILL PRODUCTS AVAILABILITY												FORMING AND FABRICATING									CORROSION RESISTANCE					
BEARING (EDGE DISTANCE = 2.0×RIVET DIA) ULTIMATE STRENGTH psi	BEARING (EDGE DISTANCE = 2.0×RIVET DIA) YIELD STRENGTH psi	ENDURANCE LIMIT psi	MODULUS OF ELASTICITY psi	BRINELL HARDNESS 500 kg load 10 mm ball	SHEET	PLATE	TUBES DRAWN	TUBES EXTRUDED	TUBES PIPE	SHAPES ROLLED	SHAPES EXTRUDED	ROD	BAR	WIRE	RIVETS	FORGINGS & FORGING STOCK	FORMING (Sheet only)	MACHINING	WELDING RESISTANCE	WELDING PRESSURE	WELDING GAS	WELDING ARC W/FLUX	WELDING ARC W/INERT GAS	BRAZING	SOLDERING	OUTDOOR ATMOSPHERES RURAL	OUTDOOR ATMOSPHERES INDUSTRIAL	OUTDOOR ATMOSPHERES MARINE	SEA WATER	AA ALLOY NUMBER	TEMPER DESIGNATION
25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56
50,400	23,400	16,000		47													A	C	C	A	B										-O
59,400	50,400	17,000		60													A	C													-H32
68,400	55,800	18,000	10.2×10^6	68	●	●	●		●			●	●	●	●		B	C	n.a.	n.a.	A	A	A	C	C	A+	A	A	A	5052	-H34
72,000	63,000	19,000		73													C	B													-H36
75,600	66,600	20,000		77													D	B	A	B	B										-H38
63,000	32,400	17,000		58													A	C	A	A											-O
63,000	28,800	17,000		63													A	C	n.a.	n.a.											-H112
70,200	54,000	18,000	10.2×10^6	67	●	●						●	●	●			B	C			B	A	A	C	D	A+	A	A	A	5154	-H32
75,600	59,400	19,000		73													B	C	A	C											-H34
81,000	64,800	20,000		78													C	B	n.a.	n.a.											-H36
86,400	70,200	21,000		80													D	B	A	C											-H38
99,000	77,400	18,000	10.2×10^6	95				●			●	●	●	●			n.a.	A	B	D	D	D	D	D	X	A	B	C	C	2011	-T3
106,200	81,000	18,000		100																											-T8
111,600	75,600	20,000	10.6×10^6	105		●	●	●	●		●	●	●	●		●	n.a.	A	D	C	D	B	C	D	X	A	B	C	C	2014	-T4
126,000	108,000	18,000		135																D											-T6
111,600	72,000	18,000	10.5×10^6	105								●	●	●	●	●	n.a.	A	D	D	D	B	C	D	X	A	B	C	C	2017	-T4
126,000	90,000	20,000		120													C	A													-T3
129,600	102,600	18,000	10.6×10^6	130	●	●	●	●	●		●	●	●	●	●		D	A	D	C	D	B	C	D	X	A	B	C	C	2024	-T36
122,400	84,600	20,000		120													C	A													-T4
59,400	36,000	13,000	10.1×10^6	62										●	●			B	A	C	A	A	A	A	A	A	A	A	A	6053	-T4
70,200	59,400	13,000		80																											-T6
63,000	37,800	14,000	10.0×10^6	65	●	●	●	●	●	●	●	●	●	●	●	●	B	B	A	C	A	A	A	A	A	A	A	B	B	6061	-T4
81,000	72,000	14,000		95																											-T6
63,000	37,800	14,000	10.0×10^6	65			●	●	●		●						B	B	A	C	A	A	A	A	B	A	A	A	B	6062	-T4
81,000	72,000	14,000		95																											-T6
45,000	23,400	n.a.		n.a.														B	n.a.												-T4
39,600	23,400	9,000		42														B													-T42
48,600	37,800	10,000		60														B	A	C	A	A	A	A	B	A+	A	A	A	6063	-T5
63,000	55,800	10,000	10.0×10^6	73			●	●	●		●							B													-T6
66,600	63,000			82														B													-T83
54,000	48,600	n.a.		70														B	n.a.												-T831
75,600	70,200			95														B													-T832
149,400	131,400	23,000	10.4×10^6	150	●	●	●	●	●		●	●	●	●		●	D	A	B	D	D	D	C	D	D	A	B	C	C	7075	-T6

NOTES TO TABLE 2-4: TYPICAL PHYSICAL, MECHANICAL AND FABRICATING PROPERTIES OF WROUGHT ALLOYS:
Data in this table on physical and mechanical properties conform to typical values established by the Aluminum Association.

The strength characteristics of non-heat-treatable *alclad* alloys listed in this table are virtually identical with those of the core alloy; strength values of heat-treatable *alclad* alloys listed are as much as 7000 psi lower, depending on the temper. However, with regard to corrosion resistance, alclad alloys exhibit superior qualities, as explained in Sections 2.2 and 3.6, and the corrosion ratings shown for the core alloys in Columns 51–54 should therefore be raised. The alloys 3003, 3004, 2014, 2024, 6061 and 7075 are available in their alclad forms as sheet and plate with claddings of 7072, 7072, 6003, 1230, 7072 and 7072, respectively.

Additional information relative to the structural applications of alloys 6061-T6 and 2014-T6 is supplied in the ASCE specifications reproduced in the Appendix.

Physical Properties: The variation of certain values for the alloys listed is rather slight. The specific gravity is usually taken as 2.70, the density (weight in pounds /in^3) is roughly 0.10, and the coefficient of thermal expansion is 13.0 x 10^{-6}. The latter value, for instance, is recommended for all computations in structural design.

Mechanical Properties: Values listed under this heading are average for various forms, sizes, and methods of manufacture, and may not describe any one particular product, because strength characteristics are influenced by these factors.

Guaranteed minimum and limiting values are specified by the individual producer, by industrial standardizing organizations and by government agencies. (See Table 2-6: ASTM Specifications for Tensile Strengths).

Local variations of values shown may be expected as a result of individual forming operations. Cold-worked sections are subject to high local strain hardening resulting in local variations of strength. Rolled and extruded materials exhibit their greatest strengths in the direction of forming.

Columns 13 and 14: Tensile Strength. Values for 2011-T3 are slightly lower for sizes greater than 1½″. Values for 2014-T6 and 2024-T4 are 15 to 20% higher for extruded products of more than ¾″ thickness. Values for 7075-T6 are about 10% higher for extruded products.

Tensile yield strength is defined as the tensile stress which produces a permanent set of 0.2% of the initial gage length.

Column 17: Ultimate to Yield Strength Ratio f_u/f_y
This value, which is not ordinarily given in tables, is considered significant because it is a measure of the safety of aluminum structures. The spread between yield and ultimate strength represents the additional safety margin of structures for which the working stress is based on the yield strength.

Columns 18 and 19: Tensile Strength-Weight Ratio. This is essentially a measure of structural efficiency representing the length in inches of a vertically suspended member which will break or yield under its own weight.

Column 20: Compressive Yield Strength. Compressive yield strength is defined as the compressive stress which produces a permanent set of 0.2% of the initial gage length.

The value for 2011-T3 is slightly lower for sizes greater than 1½″. Values shown for 2014-T6 and 2024-T4 are 15 to 20% higher for extruded products of more than ¾″ thickness. The value for 7075-T6 is about 10% higher for extruded products.

Columns 21–23: Short Column Strength Coefficient. These values are empirical coefficients found in published data.

Columns 25 and 26: Bearing Strength. These values indicate typical bearing properties as applied to riveted and bolted connections. The bearing strength is assumed as 1.8 times the tensile strength. The bearing yield strength is defined here as the bearing stress which produces a permanent set of 2% of the rivet hole diameter.

Column 27: Endurance Limit. Values are based on 5x10^8 cycles of completely reversed stress when using the R. R. Moore type of machine and specimen.

Column 28: Modulus of Elasticity. The values given are averages of the moduli in tension and compression at room temperature. The modulus of

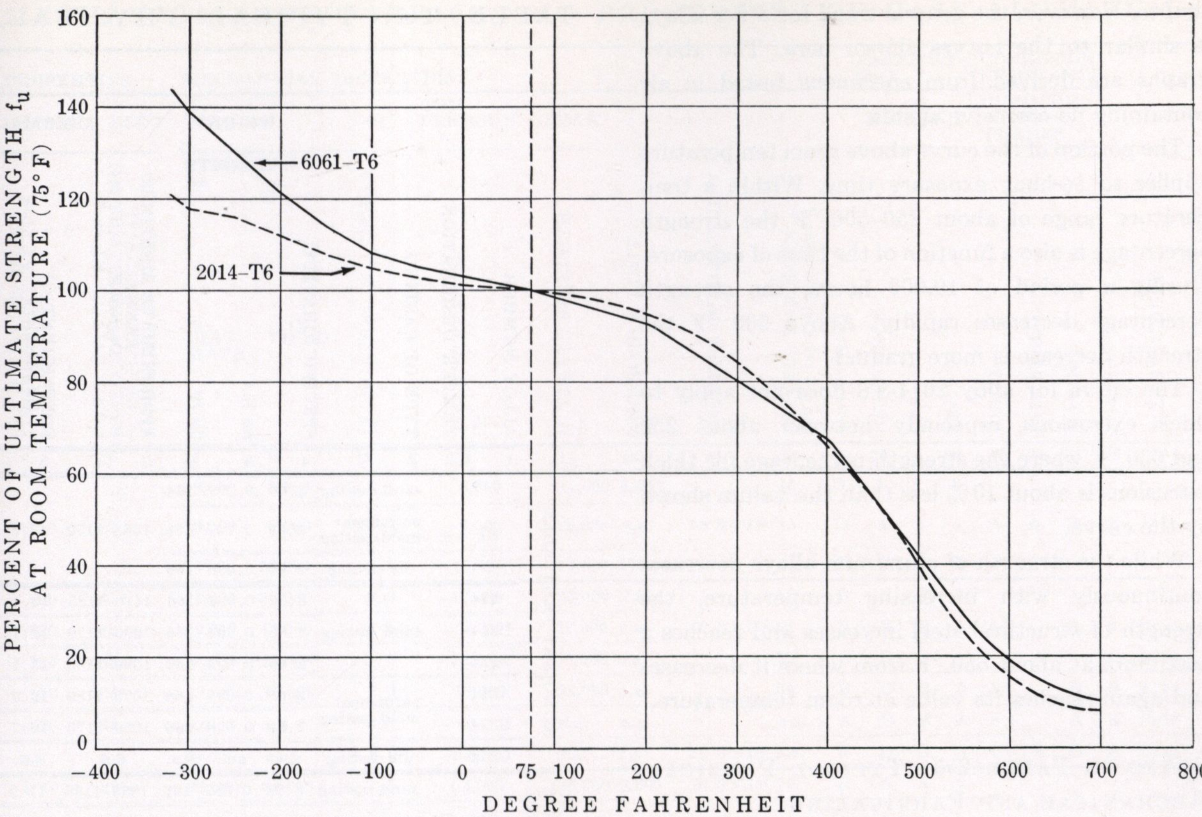


Figure 2-1: Ultimate tensile strength vs. temperature

elasticity in compression is about 2% greater than in tension. The modulus of elasticity varies inversely with temperature.

Columns 30–41: Mill Products, Availability. The various mill products listed are normally produced in the respective alloy compositions. Alloys 2014, 2024, 3003, 5050 and 6061 in their alclad forms are available in sheet and plate only.

Column 42: Forming—Column 43: Machining. Materials rated A have the best characteristics, B have the next best, etc. Alclad alloys usually have the same forming classification as their core alloys.

Columns 44–50: Joining Methods. Ratings in these columns are defined as follows:

A: Generally weldable by all commercial procedures and methods.

B: Weldable with special technique or for specific applications which justify preliminary trials or testing to develop welding procedure and weld performance.

C: Limited weldability because of crack sensitivity or loss in resistance to corrosion and mechanical properties.

D: No commonly used welding methods have so far been developed.

X: Indicates soldering is not recommended.

For additional information on welding 2014-T6 and 6061-T6, see Chapter 4 in this book.

Corrosion Resistance: An A-rating is highest, B-rating is second best, etc. Implications and use of this part of the table are discussed in Section 2.4.

Notes to Fig. 2-1: Ultimate Tensile Strength Versus Temperature:

These curves show ultimate strength variations as a function of temperature. Values are expressed in percent of room temperature (75 °F) strength. Curves shown are for the alloys 2014-T6 and 6061-T6, which are commonly used for structural

shapes. However, the general trend for other alloys is similar to the curves shown here. The above graphs are derived from specimens tested in air containing no corrosive agents.

The portion of the curve above room temperature applies to ½-hour exposure time. Within a temperature range of about 250–500 °F the strength percentage is also a function of the time of exposure. During a period of 10,000 hours, the strength percentage decreases rapidly. Above 500 °F the strength decrease is more gradual.

The curve for alloy 2014-T6 does not apply to thick extrusions, especially between about 250 and 550 °F where the strength percentage for thick extrusions is about 10% less than the values shown by the curve.

While the strength of aluminum alloys decreases continuously with increasing temperature, the strength of structural steel increases and reaches a maximum at about 550 °F from where it decreases and again reaches its value at room temperature.*

TABLE 2-5: TYPICAL PHYSICAL,

				PHYSICAL				
				WEIGHT			THERMAL	
					DENSITY			
	ALLOY NUMBER	TEMPER DESIGNATION	TYPE OF CASTING	SPECIFIC GRAVITY	lbs/in.³	lbs/ft³	APPROXIMATE MELTING RANGE Degrees F.	COEFFICIENT OF EXPANSION PER °F ×10⁻⁶ (68°–212° F)
	1	2	3	4	5	6	7	8
NON-HEAT-TREATABLE	43	—	sand casting	2.69	0.097	168		
			permanent mold casting	2.69	0.097	168	1065–1170	12.3
			die casting	2.65	0.096	166		
	214	—	sand casting	2.65	0.096	166	1110–1185	13.4
	B214	—	sand casting	2.65	0.096	166	1090–1170	12.7
	F214	—	sand casting	2.66	0.096	166	1090–1185	13.1
	A214	—	permanent mold casting	2.68	0.097	168	1075–1180	13.3
	B214	—	permanent mold casting	2.65	0.096	166	1090–1170	12.7
	C214	—	die casting	n.a.	n.a.	n.a.	n.a.	n.a.
HEAT-TREAT-ABLE	356	T6	sand casting	2.68	0.097	168	1035–1135	11.9
			permanent mold casting	2.68	0.097	168	1035–1135	11.9

NOTES TO TABLE 2-5: TYPICAL PHYSICAL, MECHANICAL AND FABRICATING PROPERTIES OF CAST ALLOYS:

Column 3: Type of Casting. Since some data vary for the different types of castings values are shown for sand castings, permanent-mold castings and die castings.

Mechanical Properties: Values listed are typical values. Guaranteed minimum and limiting values are specified by the individual foundry, by industrial standard organizations, and government agencies.

Column 12: Tensile Yield Strength. Tensile and compressive yield strengths are respectively defined as the tensile or compressive stresses which produce permanent sets of 0.2% of the initial gage lengths.

Forming and Fabricating: The ratings shown in these columns differ somewhat from those employed in the respective columns for wrought alloys; here the following code letters are used:

A: Excellent

B: Very good

C: Good

D: Fair to poor

Corrosion Resistance: An A-rating is highest, B-rating is second best, etc. Implications and use of this part of the Table are discussed in Section 2.4.

NOTES TO TABLE 2-6: ASTM SPECIFICATIONS FOR TENSILE STRENGTHS

The ASTM specifies not only ultimate and yield tensile strengths, but also chemical and physical requirements, permissible thickness variations, testing methods, etc. (See also Notes to Table A2-5 in the Appendix.)

Values shown in this table usually correspond to the properties guaranteed by the producer and, therefore, differ from those in Table 2-4 which gives typical values.

The specified values are given as minimum values, except for the annealed tempers which are given in maximum values since it is generally re-

* For further details see ANC-5 BULLETIN—STRENGTH OF METAL AIRCRAFT ELEMENTS issued by the Subcommittee on Air Force—Navy—Civil Aircraft Design Criteria of the Munitions Board Aircraft Committee.

PROPERTIES — THERMAL: CONDUCTIVITY AT 77° F btu/in./ft²/°F/hr	PROPERTIES — ELEC.: CONDUCTIVITY AT 68° F BASED ON EQUAL VOLUME % OF INTERNATIONAL ANNEALED Cu STANDARD	MECHANICAL PROPERTIES — TENSION: STRENGTH psi fu ULTIMATE	TENSION: STRENGTH psi fy YIELD	TENSION: ELONGATION IN 2 INCHES %	COMPRESSION: YIELD STRENGTH psi	SHEAR: ULTIMATE STRENGTH psi	ENDURANCE LIMIT psi	MODULUS OF ELASTICITY psi	BRINELL HARDNESS 500 Kg Load–10 mm Ball	FABRICATING: MACHINING	WELDING: RESISTANCE	WELDING: GAS	WELDING: ARC	CORROSION RESISTANCE — OUTDOOR ATMOSPHERES: RURAL	INDUSTRIAL	MARINE	SEA WATER	ALLOY NUMBER	TEMPER DESIGNATION
9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
		19,000	8,000	8.0	8,000	14,000	8,000		40	D–	A	A	A						
1020	37	23,000	9,000	10.0	9,000	16,000	n.a.	10.3×10^6	45	D–	A	A	A	A	A	B	B	43	—
		30,000	16,000	9.0	16,000	19,000	17,000		n.a.	D–	D	D	D						
960	35	25,000	12,000	9.0	12,000	20,000	7,000		50	A	B	B	A					214	—
1020	38	20,000	13,000	2.0	13,000	17,000	n.a.	10.3×10^6	50	B	B	B	A	A+		A	A	B214	—
990	36	21,000	12,000	3.0	12,000	17,000	n.a.		50	B	B	B	A		A			F214	—
930	34	27,000	16,000	7.0	16,000	22,000	n.a.	10.3×10^6	60	B	B	B	A	A		B	B	A214	—
1020	38	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.		n.a.	A	B	B	A	A+		A	A	B214	—
n.a.	n.a.	41,000	n.a.	8.0	n.a.	n.a.	n.a.	10.3×10^6	n.a.	B	D	D	D	A	A	B	B	C214	—
1050	39	33,000	24,000	3.5	24,000	26,000	8,500	10.3×10^6	70	D	A	A	A	A	A	B	B	356	T6
1050	39	38,000	27,000	5.0	27,000	30,000	13,000	10.4×10^6	85	C	A	A	A						

quired that material in the annealed temper have the maximum ductility. By specifying maximum values, complete annealing of the material can be assured.

If only one value is given in the table, it applies to all dimensions (thicknesses or diameters) covered by ASTM. Where a range of values is shown (56/64 MIN, for instance), it indicates the variations for various dimensional ranges of the product.

Inasmuch as Table 2-6 is merely a guide for quick reference, thickness ranges are not shown, and if such information is desired, reference should be made to the respective ASTM Specification.

2.4 CORROSION RESISTANCE OF ALUMINUM

One of the many favorable characteristics of aluminum and its alloys is its high resistance to corrosion. Because of this and because it is not subject to attack by rot, mildew, vermin, fungi, bacteria or the like, aluminum is widely employed in the building industry. Its use is not limited to decorative items. It is also widely employed now for many structural shapes, air ducts and other items found throughout industry. The excellent corrosion resistance of aluminum permits its use even in the highly corrosive conditions found in many chemical processing plants.

Among those alloys commonly employed in the building trades are: 1100, 3003, Alclad 3003, 3004, Alclad 3004, 5052, 5154, 6061 and 6063. All these alloys exhibit excellent corrosion resistance to industrial and marine atmospheres. Alloys 1100 and 3003 find widest use in siding and roofing. Alloys 6061 and 6063 are employed where strength and formability must be combined. Those alloys containing magnesium as the major alloying element (5052, 5154, 6063) are often specified for seacoast and marine service because they possess superior corrosion resistance in salt air.

TABLE 2-6: ASTM SPECIFICATIONS FOR TENSILE STRENGTHS

ALLOY NUMBERS: A A DESIGNATION	ALLOY NUMBERS: ASTM NUMBER	TEMPER	ASTM B209-56T ALUMINUM & ALUMINUM ALLOY SHEET & PLATE: ULTIMATE KIPS/in²	ASTM B209-56T: YIELD KIPS/in²	ASTM B210-56T ALUMINUM ALLOY DRAWN SEAMLESS TUBE: ULTIMATE KIPS/in²	ASTM B210-56T: YIELD KIPS/in²	ASTM B211-55T ALUMINUM & ALUMINUM ALLOY BARS, RODS & WIRE: ULTIMATE KIPS/in²	ASTM B211-55T: YIELD KIPS/in²	ASTM B221-56T ALUMINUM & ALUMINUM ALLOY EXTRUDED BARS, RODS & SHAPES: ULTIMATE KIPS/in²	ASTM B221-56T: YIELD KIPS/in²	ASTM B235-56T ALUMINUM ALLOY EXTRUDED TUBE: ULTIMATE KIPS/in²	ASTM B235-56T: YIELD KIPS/in²	ASTM B241-56T ALUMINUM ALLOY PIPE: ULTIMATE KIPS/in²	ASTM B241-56T: YIELD KIPS/in²
1100	990A	0	15.5 max				15.5 max		15.5 max					
		H12	14 min											
		H14	16 min				16 min							
		H16	19 min											
		H18	22 min				22 min							
3003	M1A	0	19 max		19 max				19 max		19 max			
		H12	17 min											
		H14	20 min		20 min									
		H16	24 min											
		H18	27 min		27 min								27 min	
3004	MG11A	0	29 max		29 max									
		H32	28 min											
		H34	32 min											
		H36	35 min											
		H38	38 min											
4043														
4343														
X4543														
005														
5050	G1A	0	24 max		24 max									
		H32	22 min											
		H34	25 min		25 min									
		H36	27 min											
		H38	29 min		29 m n									
5052	GR20A	0	31 max		35 max		32 max							
		H32	31 min											
		H34	34 min		34 min		34 min							
		H36	37 min											
		H38	39 min		39 min		39 min							
5154	GR40A													
2011	GB60A	T3					42/45 min	30 min*						
		T8					52 min	40 min*						
2014	CS41A	T3												
		T4					55 min	32 min*	50 min	35 min	50/55 min	30/35 min		
		T6					65 min	55 min*	60/68 min	53/60 min	60/68min	53/60 min		
2017	CM41A	T4					55 min	32 min*						
2024	CG42A	T3	64 min	42 min	64 min	42 min								
		T4	56/64 min	40 min			62 min	40 min*	57/70 min	42/52 min	60/70 min	40/48 min		
6053	GS11B	T4							25 min	14 min				
		T6							32 min	25 min				
6061	GS11A	T4	30 min	16 min	30 min	16 min	30 min	16 min*	26 min	16 min	26 min	16 min		
		T6	42 min	35 min	42 min	35 min	42 min	35 min*	38 min	35 min	38 min	35 min	38/42 min	35 min
6062														
6063	GS10A	T42							17 min	10 min	17 min	10 min		
		T5							22 min	16 min	22 min	16 min	22 min	16 min
		T6							30 min	25 min	30 min	25 min	30 min	25 min
7075	ZG62A	T6	70/77 min	60/66 min			77 min	66 min*	78/60 min	68/72 min	78/80 min	70/72 min		

* For a diameter or thickness of 0.125 in. and over.

NOTICE: Values shown as fractions here indicate ranges. Thus 42/45 indicates 42 to 45 KIPS per square inch minimum.

Alloys 2017, 2024 and 7075 are sometimes used in buildings, but they should be employed in the clad form or covered with a protective coating to provide additional corrosion resistance.

The reason for aluminum's remarkable resistance to corrosion is the very thin inert film of aluminum oxide that protects the surface. This film is formed rapidly in air. After reaching a thickness in the order of a millionth of an inch, it effectively halts further atmospheric oxidation of the metal. If this natural oxide film is broken, as by a scratch, a new protective film forms instantly in air or other oxidizing media. The oxide film increases in thickness with temperature and remains protective to the underlying aluminum even at the melting point.

Although aluminum is quite resistant to industrial atmospheres, nevertheless it may be necessary to protect the metal from certain severely corrosive environments. Thus even in exceptionally corrosive applications, it is still possible to make use of the metal's high strength-weight ratio by applying protective coatings such as organic paints, or by cladding with a sacrificial alloy (see Section 3.7). Additional protection can also be supplied by increasing the thickness and effectiveness of the natural oxide film by anodizing (see Section 3.6).

For building purposes, the common alloys (alloys whose mechanical properties may be increased by cold working) such as 1100, 3003, 5052 and 5154; and the age-hardenable alloys of the magnesium silicide type such as 6061, 6062 and 6063 are generally satisfactory and may be used in combination to obtain the desired architectural effects and structural strength.

Alloys in which copper is the major alloying element (the 2xxx series) or the alloys in the class of 7075 should be employed for building purposes only when properly protected against corrosion.

The causes can be classified into three groups: Atmospheric, electrolytic and direct chemical corrosion. Actually, atmospheric corrosion (or weathering) is caused by electrolytic or chemical action; the reason for making a separate classification is to distinguish between the uncontrolled chemical action under various atmospheric conditions and the planned use of specific chemicals.

ATMOSPHERIC CORROSION (WEATHERING): This type of corrosion is due to and depends in its degree on the type and extent of contamination of the surrounding atmosphere. It is obvious that more corrosive elements are present in an industrial or marine atmosphere than in a rural area. Table 2-4, Columns 51-54 and Table 2-5, Columns 23-26, compare the corrosion resistance of various aluminum alloys in outdoor atmospheres and in sea water. In interpreting these columns, caution is recommended not to draw unwarranted conclusions. A particular rating should not be construed as an absolute measure of corrosion resistance.

In general, it can be said that an alloy that becomes increasingly susceptible to corrosion with increased atmospheric contamination, (e.g. 2014, 2017 and 2024) should be adequately protected. As mentioned before, all of these alloys have copper as their major alloying element.

According to tests and observations made over a 10-year period in different atmospheric conditions on 1100, 3003 and 3004, the depth of penetration of atmospheric corrosion ranges from less than 1 mil for rural areas to about 4 mils for industrial areas, and up to 6 mils in seacoast locations.

These penetration figures are based on a large number of tests performed in part under the direction of the National Bureau of Standards. Except for highly localized conditions, these data are considered applicable to the environment noted. They may or may not apply where an extraordinarily high degree of contamination prevails. Thorough investigations and sound judgement are necessary when further conclusions are drawn. When using thin sheets, the above figures may be considered an approximate guide, and sheet thicknesses should be selected such that, under the most adverse conditions, the corrosion depth will not exceed 10% of the thickness. If required, a protective surface finish may be given to the metal.

The rate of corrosion is not uniform inasmuch as corrosion increases sharply during the first two years and from thereon proceeds at a much reduced rate. This reduction in rate of corrosion comes from the barrier action of accumulated corrosion products. Unless the thin film of corrosion products is

objectionable from a decorative standpoint, it can be left intact to provide valuable protection against further attack.

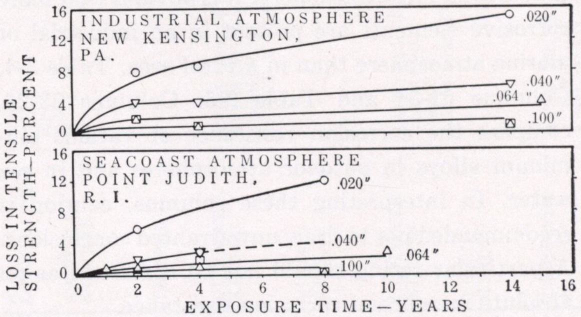


Fig. 2-2: Effect of thickness and exposure time on loss in tensile strength (for 5052-H34 panels). From Walton, Sprowls and Nock, "Resistance of Aluminum Alloys to Weathering" (Corrosion, October 1953)

Fig. 2-2 shows that the loss in tensile strength due to corrosion is, however, not only a function of the exposure time, but also of the thickness of the alloy. The expected strength performance of other thicknesses may be obtained from these curves by interpolation.

As far as the effect of atmospheric corrosion on the strength of structural members is concerned, it is obvious that it can be neglected because of their comparatively great thickness.

PROTECTION AGAINST ATMOSPHERIC CORROSION: The protection of aluminum against atmospheric corrosion depends primarily on the type and the degree of contamination of the surrounding atmosphere.

Before having recourse to a protective medium, it is advisable to investigate whether the alloy to be used is not adequate by itself. If it is necessary to provide protection, a protective finish may be used. Also consider whether the alloy in its alclad form might not be the most practical solution.

Fig. 2-3 shows the excellent resistance to corrosion of Alclad 3003-H14, Alclad 2024-T3 and 2017-T3. It will be noted that the losses in strength for Alclad 3003-H14 are higher than those for Alclad 2024-T3 and Alclad 2017-T3. This does not necessarily indicate a higher corrosion rate of Alclad 3003. The losses in strength for Alclad 2024 and Alclad 2017 are negligible because the pure aluminum cladding does not contribute to the strength. On the other hand, the cladding alloy 7072 used for 3003 does contribute to the strength and, therefore, there is a proportionally higher loss in strength.

GALVANIC CORROSION occurs with two dissimilar metals in electrical contact in the presence of an electrolyte. Galvanic attack can occur even in the atmosphere, for moisture condensed from the air will act as an electrolyte. In dry air, galvanic attack cannot occur. It is easily seen that the threat of dissimilar metal corrosion is greater in industrial and seacoast areas because the atmospheric moisture is more contaminated and thus provides a stronger electrolyte than in rural areas. In seacoast areas, the danger of electrolytic corrosion increases with the proximity to the seacoast.

Coupling two metals together in an electrolyte results in galvanic corrosion of the metal with the highest negative potential. See Table 2-7. The severity of the attack will increase with a greater difference in potential.

For example, coupling zinc to aluminum produces less corrosion than does coupling zinc to steel. However, in addition to the difference in potential, there are other factors to be considered. For example, the conductivity of the electrolyte and the possibility of the formation of high resistance barrier films on one or both metals can greatly affect the severity of attack.

It is seen from Table 2-7 that magnesium and zinc stand above the aluminum alloys and thus provide cathodic protection to aluminum. Zinc is preferred for galvanic protection of aluminum. So zinc-plated steel parts are commonly used with aluminum to reduce the effect of galvanic action.

Cadmium-plated steel is also satisfactory since there is no appreciable difference in solution potentials between cadmium and most aluminum alloys.

Alclad alloys, because of the nature of their composition, may be subject to electrolytic corrosion. A galvanic current may be generated at sheared edges or scratched areas or at spots where the cladding has been penetrated. In all such cases,

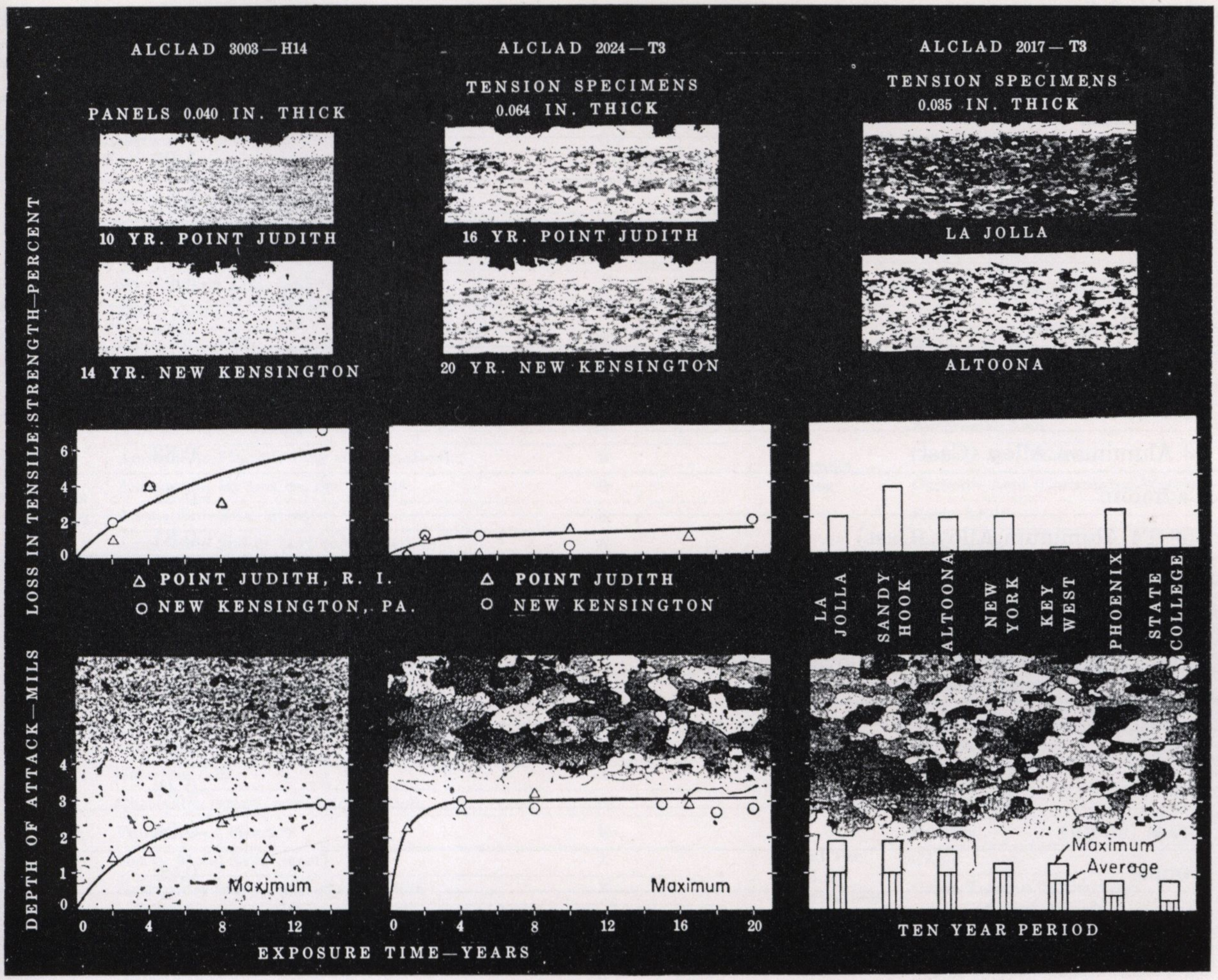


Figure 2-3: These illustrations show the outstanding resistance to corrosion of alclad products. Note in the bottom graphs superimposed on unretouched photomicrographs of the alloys, that the maximum attack does not extend beyond the alclad coatings (4.0 mils on Alclad 3003; 3.5 mils on Alclad 2024-T3 and 1.9 mils on Alclad 2017-T3) even after extended exposures in various atmospheres. This is substantiated (top) by micrographs (approx. X77) showing one surface of specimens which had been subjected to the more severe environments. Considerable cladding remains for continued electrochemical protection of core alloys. This protective effect of the alclad coatings is reflected in the small or insignificant losses in tensile strength (Center). Keller's Etch. From Walton, Sprowls and Nock, "Resistance of Aluminum Alloys to Weathering" (Corrosion, October 1953).

however, the cladding provides cathodic protection.

The rate of corrosion is generally in direct proportion to the area of the cathodic metal. It is, therefore, advisable to have the area of the cathode, (i.e. of the non-aluminum metal) as small as possible.

Protection Against Galvanic Corrosion: Galvanic attack may be prevented by one or more of the following measures:

1. By means of electrical insulation with fiber, neoprene or some other non-hygroscopic material; waterproof papers, such as asphalt-impregnated or coated paper, wax-film paper, roofing paper; or by asphalt-impregnated felt. Most commercial papers used for aluminum protection are at the same time fire and vermin-proof. Other insulating materials are plastic coatings or paints. *Caution:* Never use lead-base paints on aluminum.
2. By inserting a sacrificial alloy between the alloy

TABLE 2-7: SOLUTION POTENTIALS MEASURED IN SODIUM CHLORIDE SOLUTION

Metal or Alloy	Potential in Volts(1)
Magnesium	–1.73
Zinc	–1.00
220-T4 Aluminum Alloy (Cast) –0.92; 7072 (Wrought)	–0.96
214 Aluminum Alloy (Cast)	–0.87
5056-0 Aluminum Alloy (Wrought)	–0.87
Pure Aluminum	–0.85
5052-0 Aluminum Alloy (Wrought)	–0.85
1100-0, 1100-H18, 3003-H18, 6061-T6 Aluminum Alloys (Wrought)	–0.83
43 Aluminum Alloy (Cast)	–0.83
Cadmium	–0.82
356-T4 Aluminum Alloy (Cast)	–0.81
355-T4 Aluminum Alloy (Cast)	–0.78
195-T4 Aluminum Alloy (Cast)	–0.70
2017-T4 2024-T4 Aluminum Alloys (Wrought)	–0.68
Mild Steel	–0.58
Lead	–0.55
Tin	–0.49
Brass (60-40)	–0.28
Copper	–0.20
Stainless Steel (18-8)	–0.15
Monel Metal	–0.10
Silver	–0.08
Nickel	–0.07
Inconel	–0.04

(1) Measured in a 1 normal (5.85%) sodium chloride solution containing 0.3% hydrogen peroxide (N/10 Calomel Scale). The values vary somewhat depending on the particular lot of material investigated and on the surface preparation employed.

to be protected and the cathodic metal. An example of this method is found where aluminum piping has to be connected to another metal, for instance to copper fittings. Here a piece of sacrificial pipe of commercially pure aluminum is used. Such pipe should be located in an easily accessible place to permit replacement.

A dangerous source of electrolytic attack may be water drainage off of metals such as copper. Therefore, aluminum gutters on buildings with copper flashing must be protected by painting the copper flashing, or both the copper and the aluminum.

DIRECT CHEMICAL ATTACK: Direct chemical action may be defined as the tendency for a chemical to dissolve a metal. It is important to understand that galvanic attack is more pronounced in chemical solutions than in tap or rain water. Table 2-8 contains a list of chemicals and the suitability of aluminum for use with pure solutions of these chemicals. Such tables are necessarily limited in scope and must be considered as a guide only . . .

TABLE 2-8: ACTION OF SOME CHEMICALS ON ALUMINUM ALLOYS

1. Inorganic Reagents		REACTION ON ALUMINUM
Inorganic Acids	Boric Acid solutions, 1–5%	A
	Chromic Acid (Pure), any concentration	B
	Hydrochloric Acid	X
	Hydrofluoric Acid, 1–60%	X
	Nitric Acid	B
	Phosphoric Acid	X
	Sulfuric Acid	B
	Sulfurous Acid	B
Ammonia and Ammonium Compounds	Ammonia Gas or Liquid	A
	Ammonium Fluoride (any concentration)	B
	Ammonium Hydroxide, Sp. gr. 0.88	B
	Ammonium Salts (most)	B
	Ammonium Sulfide (any concentration)	A
Metal Salts and Hydroxides	Acid Salts	B
	Alkali Metal Bicarbonates	A
	Alkali Metal Carbonates (any concentration)	X
	Alkali Metal Hydroxides (any concentration)	X
	Arsenates (any concentration)	B
	Borax solutions, 1–3%	B
	Bromides	X
	Chlorides (all)	X
	Chromates (most), any concentration	B
	Fulminate of Mercury	X
	Heavy Metal Salts (most)	X
	Hydroxides (most), any concentration	X
	Iodides	X
	Mercury Salts	X
	Nitrates (all)	B
	Permanganates (most), any concentration	A
	Phosphates (most), any concentration	X
	Potassium Hydroxide, any concentration	X
	Potassium Nitride	A
	Salt (Sodium Chloride)	B
	Sodium Hydroxide (any concentration)	X
	Sodium Silicate (Water Glass), any concentration	B
	Sulfates	A
Water	Sea Water, 100%	See Table 7
	Steam, 100%	A
	Water (carbonated)	A
	Water (chlorinated)	B
	Water (distilled)	A
	Water (rain)	A
	Water (tap), 100%	B
Various Inorganic Reagents	Air	See Table 7
	Bleaching Solutions	X
	Fluorine	X
	Hydrogen Peroxide, 3–30% B; 70–100%	B
	Hydrogen Sulfide	A

TABLE 2-8: ACTION OF SOME CHEMICALS ON ALUMINUM ALLOYS (Continued)

1. Inorganic Reagents (Concluded)		REACTION ON ALUMINUM
Various Inorganic Reagents	Ink (iron), 100%	B
	Mercury	X
	Nitrous Gases 100%	B
	Oxygen	A
	Sulfur	A
	Sulfur Dioxide	A
2. Organic Reagents		
Organic Acids	Acetic Acid, Glacial	A
	Anthranilic Acid	X
	Carbolic Acid (Phenol)	A
	Carbonic Acid (Carbonated Water)	A
	Fatty Acids	A
	Fruit Acids	B
	Organic Acids (most)	B
Alcohols	Alcohol, Butyl	A
	Alcohol, Ethyl	A
	Alcohol, Methyl (100%)	A
	Alcohols, Higher	A
Coal Tar and its Derivatives	Aniline, liquid	X
	Anthracene	B
	Anthranilic Acid	X
	Benzaldehyde	B
	Benzene	A
	Cresol	B
	Crude Tar and its Fractions	B
	Dyestuffs (any concentration)	B
	Naphthalene	B
	Phenol (Carbolic Acid)	A
	Pyridine (acid free)	B
	Toluene	A
	Xylene	A
Foodstuffs	Beer, 100%	A
	Butter, 100%	A
	Fats (acid free)	A
	Fruit Juices	B
	Gelatine (any concentration)	A
	Milk, 100%	A
	Oil, Vegetable (chloride free)	A
	Sugar Solutions (acid free), any concentration	A
	Vinegar	A
Oils, Greases Waxes and Petroleum Products	Asphalt	A
	Castor Oil	A
	Gasoline (lead free)	A
	Gasoline (leaded)	B
	Grease (acid free)	A
	Hydraulic Brake Fluids (most)	A
	Hydrocarbons	A
	Kerosene	A

TABLE 2-8: ACTION OF SOME CHEMICALS ON ALUMINUM ALLOYS (Concluded)

2. Organic Reagents		REACTION ON ALUMINUM
Oils, Greases, Waxes and Petroleum Products	Linseed Oil	A
	Oil, Animal (acid free and chloride free)	A
	Oil, Mineral (chloride free)	A
	Oil, Vegetable (chloride free)	A
	Petroleum Products (chloride free)	A
	Tar	A
	Waxes (acid free)	A
Various Organic Reagents	Acetaldehyde	A
	Acetone (any concentration)	A
	Acetylene	A
	Camphor	B
	Carbon Disulfide	A
	Carbon Dioxide	A
	Carbon Monoxide	A
	Carbon Tetrachloride (dry)	B
	Cellulose	A
	Chloroform	X
	Copal	A
	Ether	A
	Ethyl Acetate (dry)	B
	Ethyl Chloride (dry)	A
	Ethylene Bromide	B
	Ethylene Glycol	B
	Formaldehyde (any concentration)	B
	Gas, illuminating	A
	Glue (any concentration)	B
	Glycerine (CP)	A
	Ink (dye)	B
	Methyl Chloride	X
	Nitroglycerine	A
	Refrigerants	B
	Rubber and Rubber Cements	A
	Tanning Solutions	B
	Trichlorethylene (dry)	A
	Turpentine	A
	Urea	A

DEFINITION OF RATINGS:

Chemicals rated "A": Aluminum is not seriously affected by the chemical in question at ordinary temperatures and in the absence of complicating factors, such as corrosive impurities in the chemical or galvanic action resulting from contact with dissimilar metals.

Chemicals rated "B": Aluminum should not be used without further tests or additional data. Aluminum will be satisfactory under some conditions.

Chemicals rated "X": Aluminum will not normally be satisfactory unless there are special circumstances and, in any event, should not be used without rather complete additional testing.

Rating the action of various chemicals on aluminum has certain objections, since minor changes in composition of the chemicals or operating conditions can greatly affect corrosion rates. For example, impurities, known or unknown, in the chemicals involved may cause corrosion. Before any substantial application is undertaken, trial should be made. In some cases, the application of a suitable protective coating permits the use of aluminum in contact with materials which might attack the bare metal.

Where aluminum is recommended for use ("A"), or trial is warranted ("B"), the recommendation applies to 100% concentration of the reagent unless otherwise indicated. Where aluminum is not recommended for use ("X"), the recommendation applies to any concentration of the reagent.

not as final authority. If a question exists regarding an application, always contact a specialist in corrosion problems.

Some chemical attack may occur on aluminum when in contact with wet alkaline building materials such as mortar, concrete, plaster, etc. For most of these materials, corrosive action occurs only during the stage when the material is wet prior to setting. Little or no corrosion occurs after setting. The magnesium-chloride cements are an important exception to this general rule. With these cements, an inhibitor such as sodium dichromate must always be added to prevent deterioration of aluminum in contact with them.

Where aluminum is to be buried in concrete, it is usually not necessary to paint the parts. Where aluminum parts rest against concrete, coat the aluminum surface with any non-leaded or bituminous paint.

Protection Against Chemical Attack:

1. *Contact with concrete or masonry surfaces:* Under wet or intermittently wet conditions, coats of bituminous paints or layers of asphalt-impregnated building paper or felt, or other commercially available insulating materials should be applied. Coatings of creosote and tar should not be used because of their acid contents. Where wet concrete may splash against aluminum during construction, the aluminum surface may be protected by a strippable sprayed-on coating.
2. *Contact with soil:* Although aluminum is inert when buried in many types of soils, there are some soils that cause attack, and certain electrical conditions which may cause severe corrosion. For this reason, it is recommended that buried aluminum pipe should be coated according to established pipe practice, unless experience indicates otherwise, and that the modest requirements of cathodic protection be employed.
3. *Contact with wood surfaces:* Wood should be dry and treated against moisture and rot. A layer of building paper should be inserted for added protection, or a protective primer of aluminum paint may be used.
4. *Splashes of alkaline materials:* If aluminum with

TABLE 2-9: CHOICE OF MILL PRODUCTS AND ALLOYS FOR VARIOUS FINISHED PRODUCTS

FINISHED PRODUCT	MILL PRODUCT	ALLOY NUMBER
Acoustic ceiling	Sheet	3003-H14
Air duct	Sheet	3003-H14, 1100-H16, Duct Stock
Awning	Sheet	3003-H14
Bridge floor beam	Extrusion	6061-T6
	Rolled Structurals	2014-T6
Bridge rail	Extrusion	6061-T6, 6063-T6, 6062-T6
	Casting	356-T6
Builders' hardware	Sheet	5050-0
	Casting	43, 356
	Extrusion	6063-T5
Bus bar	Extrusion	6063-T5
Cabinet	Sheet	3003-H14
Center strip, f. bridges	Extrusion	6061-T6
Coping	Sheet	3003-H14
	Extrusion	6063-T42
Cornice	Sheet	3003-H14
	Extrusion	6063-T5
Curtain wall	Sheet	3003-H14, Alclad 4043, Alclad 1235
	Casting	43
	Extrusion	6063-T5, 4043-F
Deck (corrugated)	Sheet	3003-H14
Door frame	Extrusion	6063-T5, 6063-T6
Fascia plate	Extrusion	6063-T42
	Sheet	3003-H14
Fasteners	(See specific item)	
Flashing	Sheet	3003-0
Floor beam for bridge	Extrusion	2014-T6, 6061-T6
Flue lining	Sheet	1100-H16
Garage door	Sheet	3003-H14
Grating	Bar	6061-T6
Gravel stop	Extrusion	6063-T5, 6063-T42
Grille	Sand Casting	43
	Sheet	3003-H14
	Extrusion	6063-T5
Gutter	Sheet	3003-H14
Hand railing	Extrusion	6063-T5
Hardware	(See Builders' hardware)	
Hood	Sheet	3003-H14
Insulation	Foil	1235
Jamb	Extrusion	6063-T5
Kick plate	Sheet	3003-H18
Lamp post	(See Light poles)	
Letters	Sand casting	43, 214
	Sheet	3003-H14
Light pole	Tubing	6063-T4
Lighting fixtures	Sheet	No. 1 and No. 2 Reflector Sheet
Louver	Sheet	3003-H14
	Extrusion	6063-T5
Manhole steps	Forging	6061-T6
Marquee	Sheet	3003-H14
	Extrusion	6063-T5
Moulding	(See Trim molds)	
Mullion	Sheet	3003-H14

TABLE 2-9: CHOICE OF MILL PRODUCTS AND ALLOYS FOR VARIOUS FINISHED PRODUCTS (Concluded)

FINISHED PRODUCT	MILL PRODUCT	ALLOY NUMBER
	Extrusion	6063-T5, 6063-T6
Nails	Wire	6061-T913
Name plate	Casting	43, 214
Newel	Sand Casting	43, 214
	Extrusion	6063-T5
Panel	Sheet	3003-H14
Partition	Sheet	3003-H14
	Extrusion	6063-T5
Pilaster	Extrusion	6063-T5
Railing—Bridge	Extrusion	6061-T6
—Hand	Extrusion	6063-T5
—Pipe	Extrusion	6061-T83
Relief panel (sculptural)	Casting	43
Rivet	Wire	2024-T4, 6061-T6
Roofing—Corrugated	Sheet	Special
—V-crimp	Sheet	Roofing Alloys
Scaffold	Pipe	6061-T6
Screen	Wire	Alclad 5056-H392
Screws	Screw Machine Stock	2911-T3, 2017-T4
Seat brackets (stadium)	Casting	356-T6
Shade screening	Sheet	5052-H38 Alodized
Shingle	Sheet	3003-H14
Siding	Sheet	3003-H14
Signs	Sheet	6061-T6
Sill (Window-)	(See Window Sill)	
Skylight	Extrusion	6063-T5
Spandrel	Sand Casting	43
(See Curtain Wall)	Extrusion	6063-T5
	Sheet	Alclad 3003-H14
Store front	Extrusion	6063-T5, 6063-T6
Storm window	(See Window)	
Structural shape	Extrusion	2014-T6, 6061-T6
	Rolled Shape	6061-T6, 2014-T6
Switch plate (Wall)	Sheet	3003-H14
Sunshade	Sheet	3003-H14
Termite shield	Sheet	3003-H14
Terrazzo strip	Sheet	3003-H14
Threshold	Extrusion	6063-T5
Tiles	Sheet	3003-H14
Transformer vault frame sections	Extrusion	6063-T5
Tread plate	Sheet	6061-T6
Trim moulds	Extrusion	6063-T5
Vapor barrier	Foil	1235-0
Venetian blind	Sheet	5052-H18
Wall facing (tongue & groove)	Casting	43
	Extrusion	6063-T5, 6063-T6
Weatherstrip	Sheet	5052-H38
Window	Extrusion	6063-T5, 6063-T6
		6061-T6
Window sill	Extrusion	6063-T5
Window stools	Extrusion	6063-T5
	Sheet	3003-H14

a natural finish is in danger of being stained by splashes of alkaline material, an alkali-resistant strippable methacrylate type lacquer may be used for temporary protection.

2.5 FINISHED PRODUCTS FOR THE BUILDING INDUSTRY. CHOICE OF ALLOY

Table 2-9 lists various finished products with recommended mill products and alloys. The recommendations are made on the basis of practical experience, but one should keep in mind that the alloys shown may depend on a certain set of conditions, and modifications may be advisable. Thus, in selecting an alloy, this table should be used as a starting point rather than as conclusive data. The recommended alloy or alloys should be looked up in Table 2-4 (for wrought products) or in Table 2-5 (for cast products), and one should verify whether all requirements for the desired product are fulfilled; another alloy may be substituted if its overall characteristics appear to be better.

Applications of the various products are shown pictorially in this volume or in Volume I.

BIBLIOGRAPHY

THE ALUMINUM DATA BOOK by Reynolds Metals Company—1954.

ALCOA ALUMINUM AND ITS ALLOYS by Aluminum Company of America—1950.

KAISER ALUMINUM SHEET AND PLATE PRODUCT INFORMATION by Kaiser Aluminum & Chemical Sales, Inc.—1953.

HANDBOOK OF ALUMINUM ALLOYS by Aluminum Company of Canada—1951.

DISCUSSION OF THE EFFECTS OF MINOR ALLOYING ELEMENTS ON ALUMINUM CASTING ALLOYS by W. Bonsack—ASTM Bulletin, August 1942.

ALUMINUM AND ITS ALLOYS IN BUILDING by Aluminum Development Association—1953.

NOMENCLATURE: A GLOSSARY OF TERMS FOR ALUMINUM SHEET & PLATE AND ALUMINUM EXTRUDED AND TUBULAR PRODUCTS by the Aluminum Association—April 1952.

ALUMINUM-ZINC-MAGNESIUM ALLOYS—THEIR DEVELOPMENT AND COMMERCIAL PRODUCTION by E. H. Dix, Jr.—American Society for Metals, Transactions 42, 1950—pp. 1057/127.

CHARACTERISTICS OF SOME ALUMINUM-ZINC-MAGNESIUM-COPPER CASTING ALLOYS, by H. Y. Hunsicker and W. E. Sicha—American Foundrymen's Society, Transactions 58, 1950—pp. 333/45.

ALUMINUM HEAT TREATING by Reynolds Metals Company—1954.

REYNOLDS ALUMINUM MILL PRODUCTS CATALOG by Reynolds Metals Company.

ALCOA ALUMINUM ALLOYS AND MILL PRODUCTS by Aluminum Company of America.

A REVIEW OF INFORMATION ON THE MECHANICAL PROPERTIES OF ALUMINUM ALLOYS AT LOW TEMPERATURES by K. O. Bogardus, G. W. Stickley and F. M. Howell—National Advisory Committee for Aeronautics, Technical Note 2082, May 1950.

BEARING STRENGTH OF SOME ALUMINUM-ALLOY PERMANENT MOLD CASTINGS by E. M. Finley—National Advisory Committee for Aeronautics, Technical Note 2312, February 1951.

FATIGUE PROPERTIES OF CAST ALUMINUM ALLOYS by R. L. Templin, F. M. Howell and J. O. Lyst—Product Engineering 23, May 1952—pp. 119/23.

ASTM STANDARDS ON LIGHT METALS AND ALLOYS by American Society for Testing Materials.

THE ROLE OF POLARIZATION IN ELECTROCHEMICAL CORROSION by G. C. English, R. H. Brown and R. D. Williams—Corrosion 6, 1950—pp. 186/95.

ALUMINUM ALLOYS FOR OFFSHORE PIPE LINES by D. O. Sprowls and E. T. Wanderer—Corrosion 8, 1952—pp. 227/33.

ALUMINUM ALLOY CASTINGS—THEIR FOUNDING AND FINISHINGS by E. Carrington, M.Sc.—Charles Griffith & Co., Ltd., London—1946.

MANUAL OF ALUMINUM CASTING ALLOYS by Aluminum Research Institute of Chicago—1947.

THE COST OF CORROSION IN THE UNITED STATES by H. H. Uhlig—Corrosion 9, 1950—pp. 29-32

ALUMINUM FOR COPPER: GREATER CORROSION RISKS? by Dr. H. A. Liebhafsky and Dr. E. W. Balis—General Electric Review, March 1953—pp. 12-16, 61.

COMBATING CORROSION IN CHEMICALLY CONTAMINATED ATMOSPHERES WITH ALUMINUM ALLOYS by W. W. Binger, R. H. Wagner and R. H. Brown—Maintenance, August 1953—pp. 8-9.

CORROSION OF ALUMINUM ALLOYS BY EXHAUST GASES by Fred M. Reinhart—Corrosion. December 1954—p. 421.

ALUMINUM "SELF-STOPS" CORROSION by C. J. Walton, D. O. Sprowls and J. A. Nock, Jr.—Steel, Sept. 7, 1953—pp. 134/36.

RESISTANCE OF ALUMINUM ALLOYS TO WEATHERING by C. J. Walton, D. O. Sprowls, and J. A. Nock, Jr.—Corrosion, Oct. 1953.

SERVICE EXPERIENCE OF THE EFFECT OF CORROSION ON STEEL-CORED ALUMINUM OVERHEAD LINE CONDUCTORS by J. S. Forest and J. M. Ward—Engineer 197, January 29, 1954—pp 170/71.

RADIOACTIVE TRACERS IN THE STUDY OF PITTING CORROSION ON ALUMINUM by P. M. Aziz—Electrochemical Society Journal, March 1954—pp. 120/23.

CORROSION TEST OF ALUMINUM AND ITS ALLOY SHEETS IN ATMOSPHERE & SEA WATER by R. Kawachi—Chem. Abstr. 48, June 10, 1954—p. 6362.

CORROSION TESTS ON ALUMINUM ALLOYS by E. M. Mulders, W. G. R. de Jager and J. W. Boon—Abstr. Bull. (Aluminum Ltd.) 25, August 1954—p. 542.

ANTI-CORROSION ADVANCES IN LIGHT METALS by E. D. Porro—Light Metal Age, August 1954—pp. 12-13, 29.

PITTING CORROSION CHARACTERISTICS OF ALUMINUM by P. M. Aziz & H. P. Godard—Corrosion, September 1954—pp. 269/72.

CHAPTER 3: THE PRODUCTION, FABRICATION AND SURFACE FINISHING OF ALUMINUM MILL PRODUCTS AND CASTINGS

The purpose of this chapter is to provide a basic understanding of the production, fabricating and finishing processes, as well as of the terminology employed. It should be an aid in selecting and specifying a suitable and economical process, and in avoiding designs which do not take into consideration the inherent advantages of the material. As with any material, the designer must be fully aware of the important factors in fabricating aluminum . . . converting aluminum mill products into finished end products. Therefore this chapter contains such related data as minimum bend radii, standard dimensional tolerances, and the like.

The selection of a particular mill product or fabricating process must take into consideration not only design objectives but cost factors as well. Factors influencing costs are included wherever possible.

While similar considerations apply to designing in general, they are of particular importance in the design of aluminum shapes because of the lower fabricating and forming costs. Due to the relatively small number of standardized aluminum shapes, the designer of aluminum shapes must assume more responsibility than the steel designer who has a multitude of standardized steel products at his disposal.

These problems are especially vital in the design of extruded shapes. The extrusion process which, in terms of design methods, is the least familiar to architects and engineers working with other materials, such as steel, concrete or timber, offers the greatest possibilities in aluminum design.

On the other hand, because of the low initial die cost and the flexibility of the extrusion process, the designer may be tempted to employ it where its use is not justified. It is with a view to the imaginative design potentials on the one hand and possible pitfalls on the other that the extrusion process is discussed in detail in this chapter.

The greater part of aluminum products used in the building industry are wrought products. There are, however, a number of applications where cast products are also quite suitable. Such applications include architectural hardware, ornamental facing work, spandrel panels, escutcheons and the like. Table 2-9 lists aluminum mill and foundry products most suitable for various end products. Column 3 of this table also indicates the aluminum alloy which is recommended on the basis of general experience in the trade. Inasmuch as the choice of a certain mill or foundry product depends upon certain determining qualities, the use of Tables 2-4 and 2-5 is recommended in conjunction with Table 2-9.

There are a large variety of surface finishes available. The most important ones are described in this chapter, so that the engineer or architect may familiarize himself with their properties and characteristics. When choosing an appropriate surface finish, he may avail himself of Table 3-6 which lists surface treatments for various requirements such as appearance (color or texture), surface protection, and the like. Estimated costs of the most common surface treatments are given in Table 3-7.

3.1 DEFINITIONS OF INGOT, WROUGHT ALUMINUM MILL PRODUCTS AND CASTINGS

INGOT:

Primary Aluminum Ingot obtained from the reduction pots (see Section 1.2) is commercially pure aluminum. After it has been remelted and alloyed to

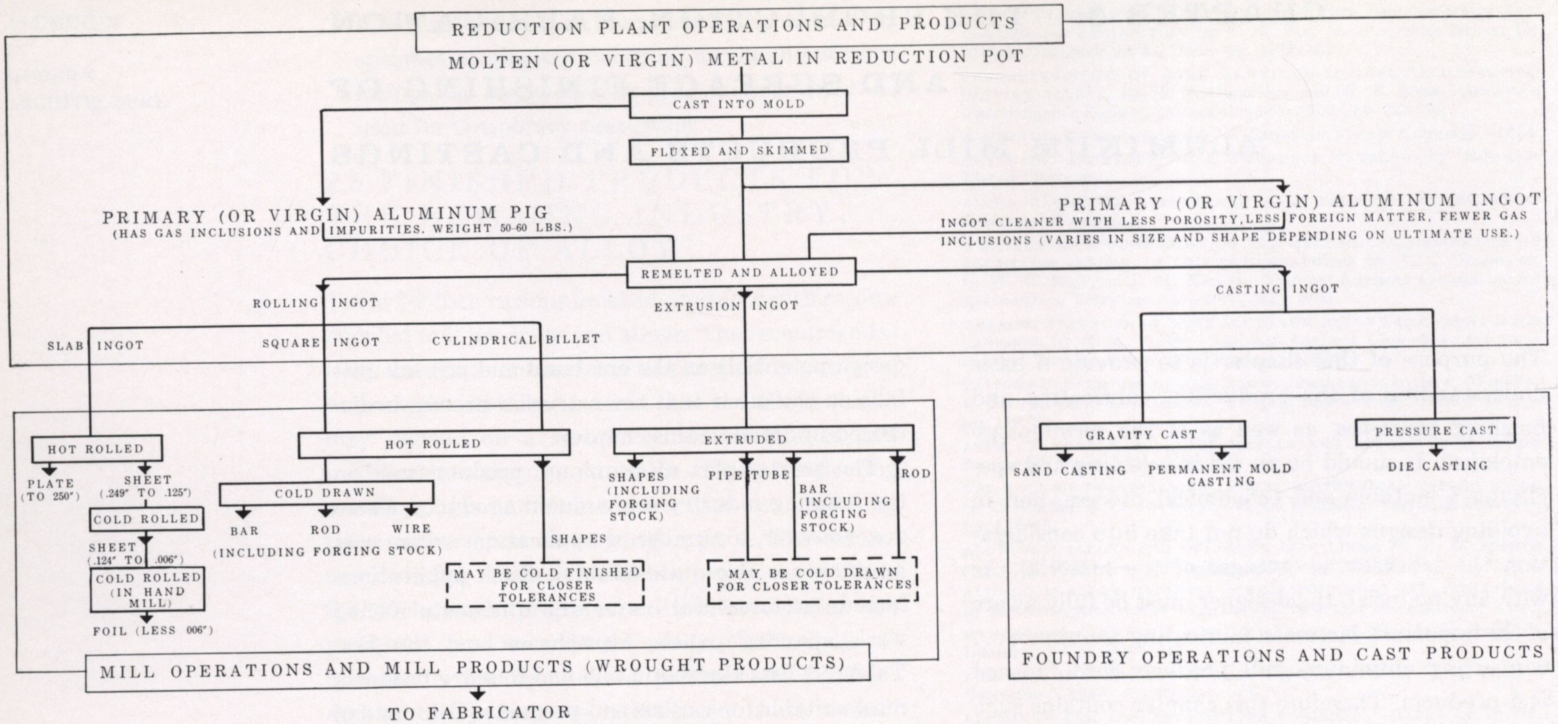


Figure 3-1: Sequence of operations in the production of ingots, wrought products and castings.

a controlled composition for the purpose of hardening and strengthening, it is then cast into ingots of various sizes and shapes depending upon their ultimate use. There are several types of ingots which include the following:

Aluminum Rolling Ingot: For producing sheet, plate, wire, rod, bar or structurals.

Aluminum Extrusion Ingot: For producing extruded rod, bar, shapes, tube and pipe.

Aluminum Casting Ingot: Used in the foundry where it is remelted for casting.

Aluminum General Purpose Casting Ingot: In this type of ingot the composition limits for certain elements, notably iron, manganese, zinc, tin and nickel, are such that the ingot may be produced by reclaiming suitable scrap; or by remelting high-iron, high-silicon aluminum pig; then the required alloying elements are added and, after fluxing and skimming, the metal is poured into molds.

WROUGHT ALUMINUM MILL PRODUCTS are basic structural forms of aluminum, made at the aluminum producer's mill. They include plate, sheet, foil, bar, rod, wire, extruded sections, structural shapes, tube, pipe and forging stock. Mechanical properties of such materials are developed by alloying, hot working, cold working or heat treatment, or by combinations of these processes.

Plate is a solid section hot rolled to a thickness of 0.250-inch or more, in rectangular form with either sheared or sawed edges.

Plate Circles are plate material cut into circular form.

Sheet is a solid section rolled to a thickness range of 0.006-inch to 0.249-inch inclusive, supplied with sheared, slit or sawed edges. Flat sheet is furnished in rectangular form with sheared, slit or sawed edges, which may be flattened by any standard method. Coiled sheet is a product rolled to finished gauge and slit to finished width in continuous strip of at least several hundred feet length, and is wound on an arbor or core.

Sheet Circles are sheet material cut into circular form.

Foil is a solid section of aluminum 0.0059-inch or less (0.010-inch or less for 99.35–99.80 percent

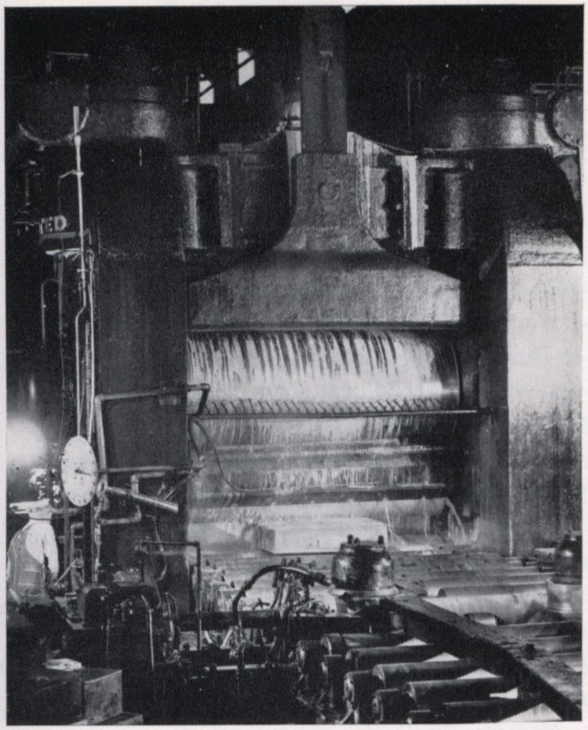


Figure 3-2: First rolling operations widen out the slab by cross-rolling and reduce its thickness to about ¾ inch.

aluminum) in thickness and is usually supplied in the form of coils.

Extruded Sections include rod, bar, tube or any shape produced by the extrusion process.

Structural Shapes are solid shapes used as load-bearing members. They include angle and channel sections, I-beams, H-beams, Tees, Zees and others.

Rod refers to round solid sections that are ⅜-inch or more in diameter.

Bar is a solid section whose cross-section has some shape other than round, such as square, hexagonal, rectangular and so on, and whose greatest diameter is ⅜-inch or more.

Wire is any solid section whose cross-section diameter (or greatest dimension) is less than ⅜-inch. Cross-section may be a round, square, hexagon, octagon, rectangle or other shape.

Tube is a hollow product with a round, square, rectangular, hexagonal, octagonal or elliptical cross-section with sharp or rounded corners, and whose wall is of uniform thickness except as affected by corner radii.

Tube Stock is a semi-finished tube intended for subsequent reduction in cross-section.

Pipe is a tube having certain standardized combinations of outside diameter and wall thickness, commonly designated by "Nominal Pipe Sizes" and "A.S.A. Schedule Numbers."

Forging Stock and Forgings are rod, bar or other sections suitable for subsequent change in cross-section by hot working in a shaped die. The product obtained is called a *forging*.

CAST PRODUCTS are produced by pouring molten metal into molds of desired shape. The mechanical properties of some castings may be improved by heat treatment. Cast products are manufactured in the foundry and include sand castings, permanent-mold castings and die castings.

3.2 THE PRODUCTION OF WROUGHT PRODUCTS AT THE MILL

HOT AND COLD ROLLING: Hot rolling is performed in mills which essentially consist of steel rollers through which aluminum ingot, heated to soften it, is passed until it is reduced to the desired size or shape. Hot rolling is continued until thicknesses of about 0.125-inch are obtained. Further reduction in thickness is accomplished by cold rolling. Cold-rolled material has a better finish and increased strength and hardness as compared with hot-rolled material. The type of rolling ingot to be used depends on the shape of the mill product. Plate, sheet and foil are rolled from flat rectangular ingot (slab ingot), structural shapes from rectangular or cylindrical billets, rod and bar from round or square-shaped ingot.

Plate (minimum thickness 0.250-inch) is made from a slab which is hot rolled in a reversing mill until reduced to a thickness of about 0.750-inch (see Figure 3-2). Further rolling operations are performed in a continuous hot mill.

Plate is ordinarily available in sizes of 36 x 96 inches, some thicknesses also in 48 x 144. Manufacturing limits generally extend up to 72 inches in width and up to 360 inches in length. Special sizes are also available upon request. Further informa-

tion may be obtained from the producer's catalog.

Sheet is likewise rolled in a hot mill to about 0.125-inch. Thinner gauges are obtained by cold rolling for additional strength and better finish.

Flat Sheet is ordinarily available in dimensions ranging between 24 x 72 and 48 x 144, depending on the thickness. Manufacturing limits are about 48 inches in width and 220 inches in length, depending upon thickness. Special sizes are available upon request.

Coiled Sheet is usually supplied in thicknesses up to .125-inch, and widths up to 62 inches, depending upon thickness.

In addition to flat and coiled sheet, there are certain types of special purpose sheet, such as Utility Sheet, Corrugated Sheet, Non-Earing Sheet, Architectural Sheet, Reflector Sheet, Clad Sheet and others.

Utility Sheet is an aluminum alloy similar to 1100 primarily developed for heating and air-conditioning ductwork. It is produced in only one temper with sufficient ductility to take a Pittsburgh lock seam. It has forming characteristics similar to 1100-H16 and can be used in many sheet applications where its temper will prove suitable, provided maximum corrosion resistance and surface appearance are not required.

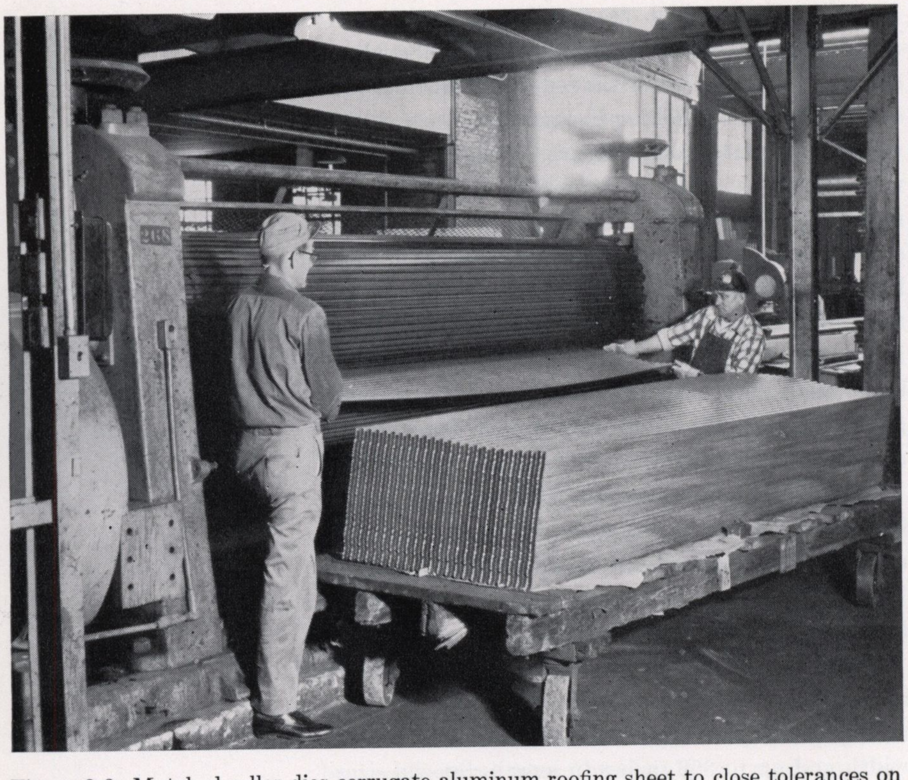


Figure 3-3: Matched roller dies corrugate aluminum roofing sheet to close tolerances on high production basis. Operators merely feed sheet to work rolls.

Its flatness and surface appearance are not guaranteed to be of the same high quality as standard aluminum alloys. It is produced in flat sheet or coils with plain surface or embossed patterns.

Manufacturing limits for utility sheet extend up to 48 inches in width and up to 144 inches in length, depending on thickness. Coil sheet comes in widths from 1 to 48 inches.

Corrugated Sheet is produced by cold forming in a press brake or by means of corrugating rolls as shown in Figure 3-3. It is generally known as roofing or siding sheet in accordance with its most frequent application. (See Sections 7.1 and 7.2.) Corrugations extend lengthwise the sheet. For special applications, curved sheet can be supplied with the curvature across the width of the sheet.

Non-Earing Sheet is of a type that prevents wavy symmetrical projections (ears) formed in the course of deep drawing or spinning. Non-earing sheet is available flat, coiled or in circles, and in thicknesses from .006 to .064-inch. Flat sheet is available in widths ranging up to 60 inches and lengths up to 144 inches. Coiled sheet is furnished in widths up to 62 inches.

Aluminum Foil is made by rolling sheet thinner and thinner in hand mills. The most common application of foil in the building industry is for heat insulating purposes and vapor barriers.

Foil is available in rolls with a coverage of 250 square feet. They usually come in widths of 25, 33 and 36 inches and in weights of 15 pounds and 11 pounds per roll.

Structural Shapes are hot rolled by means of special rolls which produce the desired shape; for example, H-beams are rolled on a series of butterfly-grooved rolls. The more complicated structural shapes require a greater number of passes to prevent undue reduction of the metal beyond its limit of plastic flow.

Finishing operations include roller or stretch straightening and when required, the rolled shapes

may be drawn through dies to obtain better surface finish and closer dimensional tolerances.

Rolls for producing structural shapes are relatively expensive since they involve the use of considerable metal with a high degree of machining and finishing to get the contours desired. When special shapes are required, the volume of material should warrant the comparatively high tooling costs. The border line depends entirely upon how complicated the shape is and the tooling cost. Generally, extruded structural shapes are cheaper because of lower tooling costs.

Standard rolled structural shapes include equal angles, unequal angles, channels and sometimes I-beams. They are usually supplied in 2014 and 6061 alloys. Other structural shapes are available as extrusions. For properties of structural shapes, see Appendix.

Rod and Bar are produced by hot rolling (see Figure 3-4) to a size larger than specified and then are cold drawn through a die for a better finish and closer dimensional tolerances. Sometimes the cold finishing is omitted.

Standard rolled rod is supplied in diameters from 1⁹⁄₁₆ to 6 inches, while cold-finished rod comes in diameters from ⅜ to 2 inches.

Rod for special purposes includes forging stock, redraw rod, rivet rod and screw machine stock (rounds).

Forging Stock is always supplied in the as-fabricated condition or "–F" temper. It must always be specified as "forging stock" to avoid confusion with similar material to be used for other purposes.

Forging rod is nearly always rolled. Forging bar may be rolled or extruded. Forging shapes are usually extruded, but may be rolled where the volume of material justifies the roll cost.

Commercial sizes of round forging stock range from ⅜ to 8 inches in diameter.

While forging stock is produced in the mill, forgings themselves are made and fabricated in forge shops.

Redraw Rod is an as-fabricated rod suitable for further drawing to produce conductor wire.

Rivet Rod is usually available in all diameters up to 0.609-inch.

Rounds come in sizes from ⅛ to 3⅜ inches.

Bar is commercially available as square bar (round or square-edge), square-edge rectangular bar, and hexagonal bar.

Cold-finished *square bar* comes in sizes from 0.375–1.500 inches, usually in increments of ¹⁄₁₆-inch. *Square-edge rectangular bar* is supplied in widths from ¾ to 3⅛ inches and thicknesses from ¼ to 1 inch. *Hexagonal bar* is made in sizes from 0.375 to 1.625 inches (distance across flats).

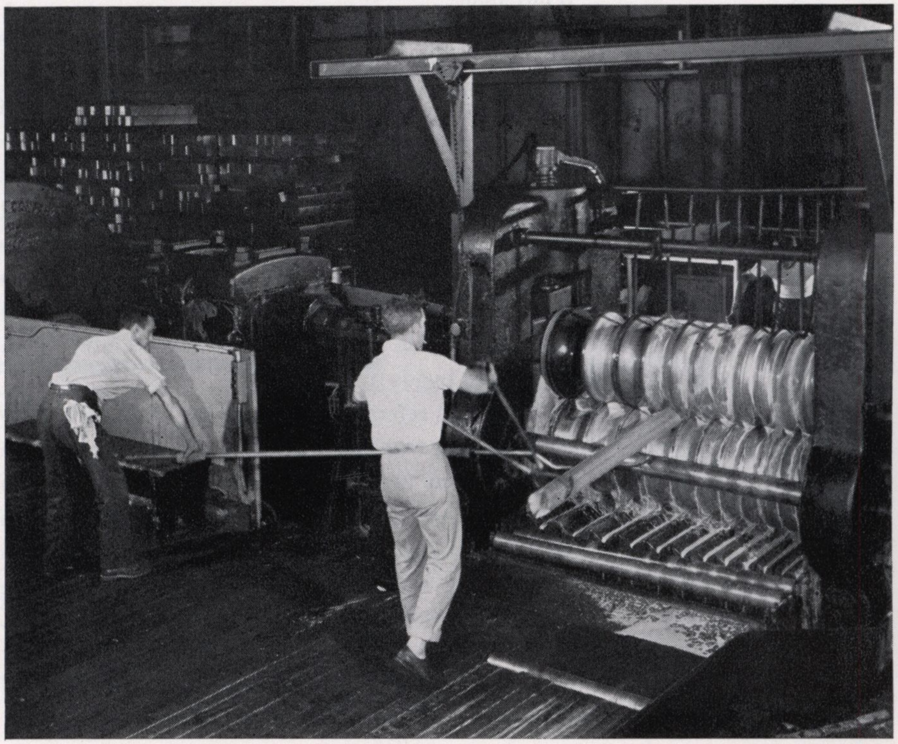


Figure 3-4: A square ingot of aluminum has been heated to soften it and is being rolled in a 3-high mill to reduce its cross section and lengthen it. Bar is passed successively back and forth through smaller and smaller die openings to obtain reduction desired. Note how die openings in rolls become smaller toward right end of the rolls.

COLD DRAWING: As previously explained, the main purpose of cold finishing (cold drawing) is to obtain closer dimensional tolerances and a better surface finish.

Wire products which by necessity have to be kept within close tolerances are cold drawn by pulling rod, which has been hot rolled to ½-inch diameter or less, through a series of progressively smaller dies to obtain the desired dimensions.

Round wire is drawn to a diameter of 0.03-inch, hexagonal wire is usually available in 5⁄16-inch and ¼-inch (distance across flats); flattened wire in thicknesses from .062 to .093-inch for a width range of .375 to .625-inch, and in thicknesses from 0.94 to .187-inch for a width range of .250 to .625-inch. Welding wire is supplied in diameters from 0.030 to 0.250-inch. Rivet wire is available in a diameter of 0.061-inch.

The cold-finishing of bar and rod is sometimes referred to as cold drawing.

Tube drawing is similar to drawing bar and rod in that chain pull draw benches are utilized. The difference lies in the fact that the tube is hollow. A mandrel with one end fixed and a bulb attached to the other is used. The tube is threaded over the mandrel which is positioned in the center of the die so that the tube may be drawn over the mandrel bulb but inside the die orifice, maintaining close tolerances inside and out.

"Sinking" refers to tube drawing without a mandrel. Sinking results in less tube runout because the inside surface metal tends to sink, thus building up the wall thickness. Sinking is considerably more economical since production is increased over bulb drawing by three times. However, it can only be utilized where inside tolerances are of little concern.

EXTRUDING is a process by which aluminum is squeezed out through a die opening. The ejected or "extruded" aluminum assumes the same size and cross-section as the die opening. Before extruding, the metal is heated to a plastic state. Extruded products include rod, bar, shapes of uniform cross-section, and seamless tube.

The extrusion is done in hydraulic presses capable of exerting pressures up to 14,000 tons. Figures 3-5 and 3-6 show details of a typical press and die.

When extruding tube and pipe, extrusion billets may be cored during casting to produce a hole throughout their length, or they may be cast solid and the hole drilled or bored. The same procedure as described above is then followed, except that a mandrel is attached to the hydraulic ram. When the ram is in the extruding position, the mandrel extends through the hole in the billet and into the die orifice. As the ram advances, metal is forced through the orifice and around the mandrel which then determines the inside dimensions of the resultant seamless tube or pipe.

Extruded shapes emerge from the press in lengths up to 110 feet. They are then heat treated, straightened and cut. Figure 3-7 shows a few of the shapes that have been produced by the extrusion process. Notice that many of these shapes are hollow.

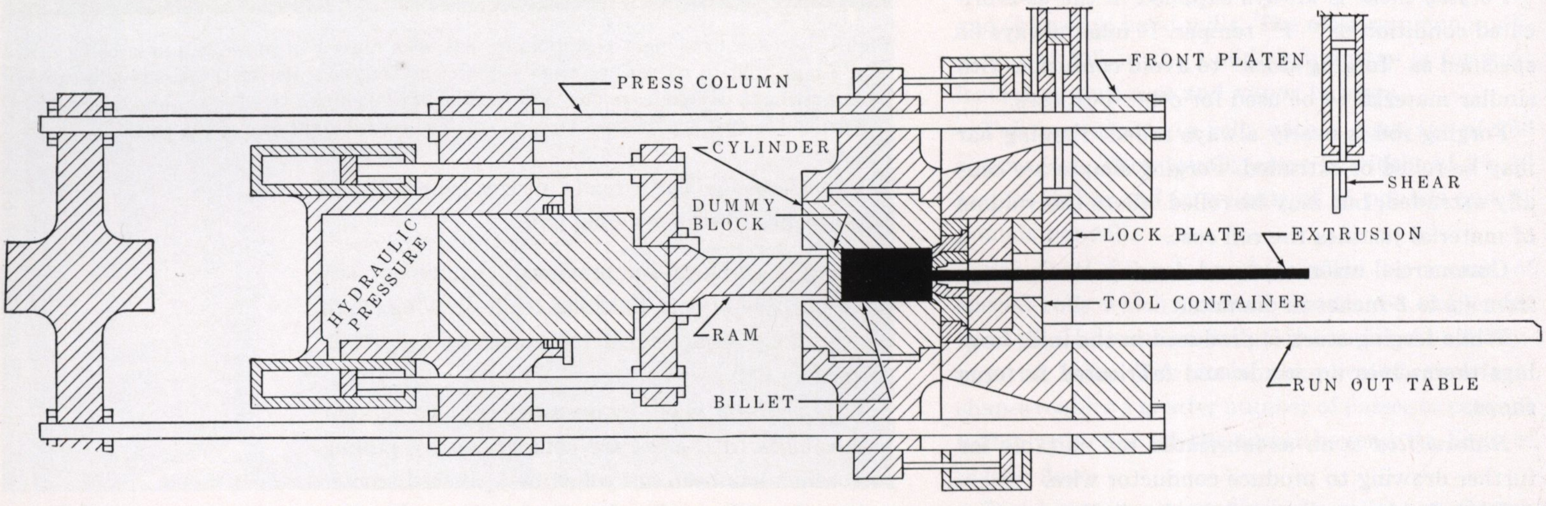


Figure 3-5: This is a typical extrusion press used for producing aluminum shapes. The hydraulically operated ram pushes the hot aluminum billet through the die opening which has the desired cross section. A typical set of extrusion tools is shown in detail in Figure 3-6.

Selection of Extruded Shapes: According to their geometry, extrusions are classified as solid, semi-hollow, and hollow. The hollow shapes are among the more difficult to produce (see Figure 3-8).

It is suggested that the engineer designing an extrusion check with the manufacturer first, as a stock die may already be available. This will save time

b) Semi-hollow sections with unbalanced die tongues.

c) Sections that include extreme variations in thickness.

d) Hollow shapes with very unsymmetrical voids, or with inadequate sections between voids.

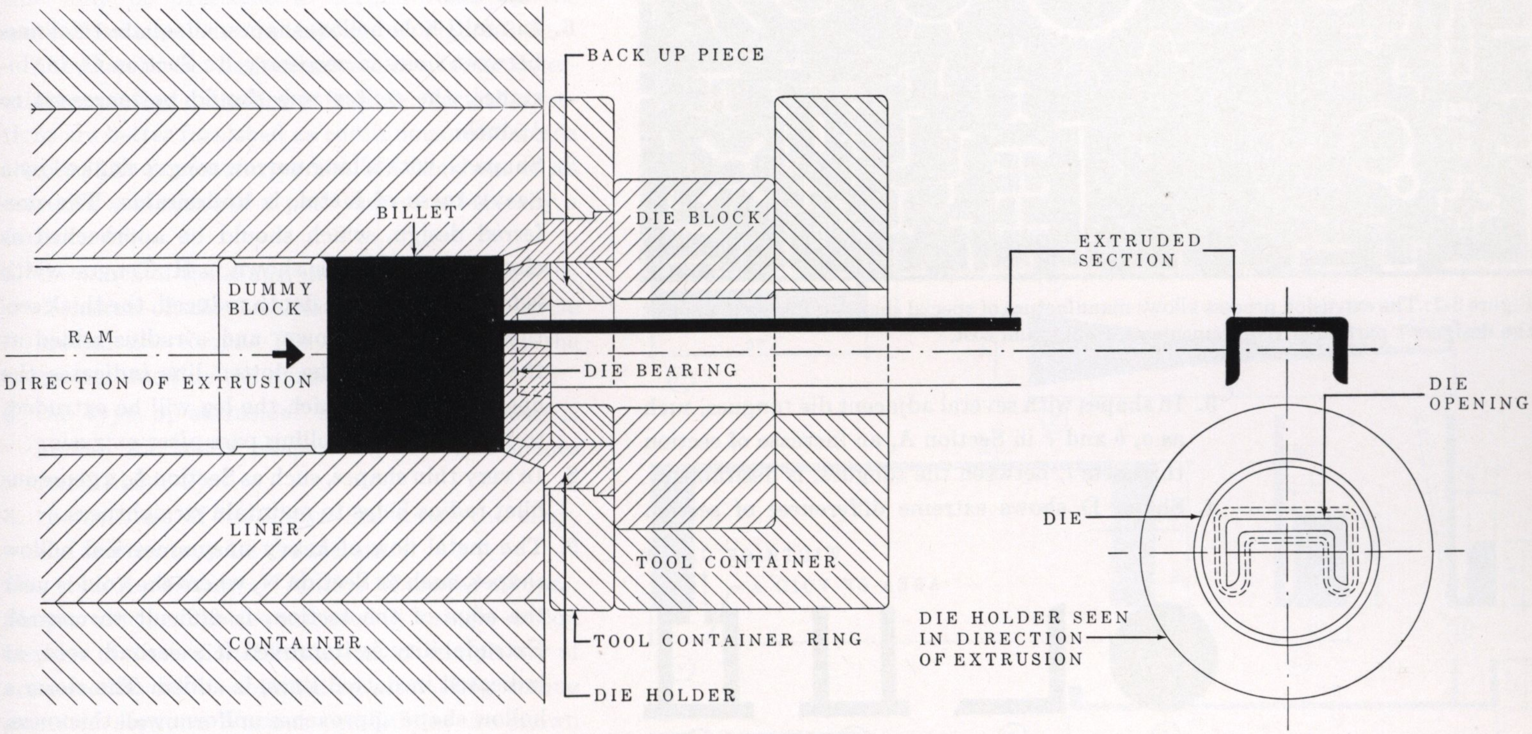


Figure 3-6: This detail shows a typical set of steel tools for producing aluminum shapes in an extrusion press. They consist of the die, back-up block, die holder, die block and tool container. Extrusion billets range in diameter from 4 to 11 inches, or more.

and cost. If, on the other hand, a special die is necessary, it is good practice to consult with the manufacturer first, so that all factors involved in the extrusion process may be taken into account. The following data will serve to point out some of the production considerations.

Non-uniform metal flow may occur in extruding heavy and thin sections simultaneously in the same die because of friction on the die walls.

In general, the following conditions should be avoided:

a) Thin sections in a large circumscribed circle.

Examples of these conditions, pictorially shown in Figure 3-9, are as follows:

1. Thin-walled shapes inside large circumscribed circles, such as Sections A and K, are difficult to straighten. A slight increase in wall thickness or stiffening ribs as indicated in Section K by dotted lines can help remedy this condition.
2. Shapes requiring large overhanging die tongues, as illustrated in Sections A, B and I, create die problems. If possible, width of the tongue (shown as "*w*" in Sections A and B) should be increased to permit greater rigidity of die.

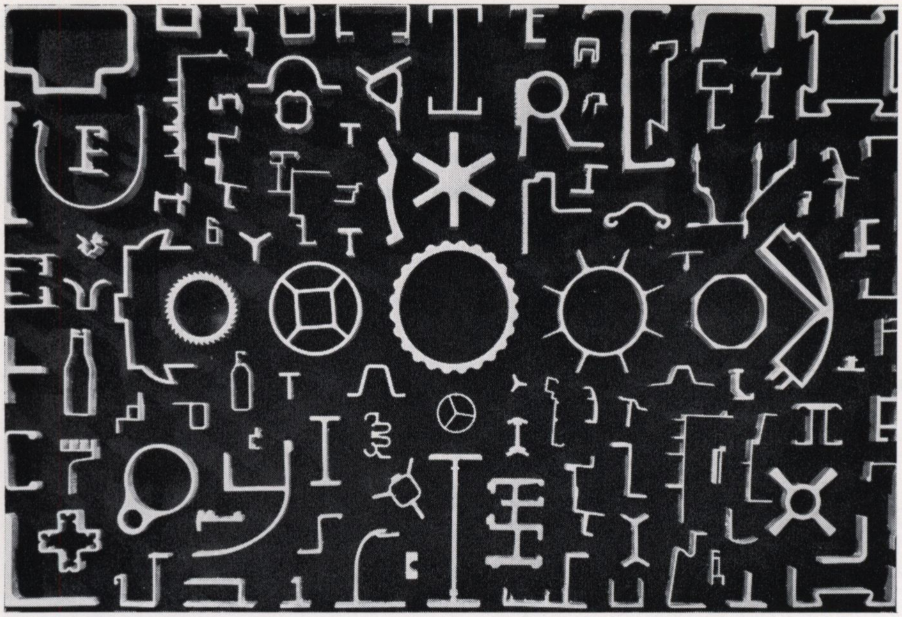


Figure 3-7: The extrusion process allows manufacture of special shapes tailormade to meet the designer's particular requirements at a minimum cost.

3. In shapes with several adjacent die tongues, such as *a*, *b* and *c* in Section A, an increase of section thickness *t*, between the tongues, is desirable.
4. Shape D shows extreme differences of section

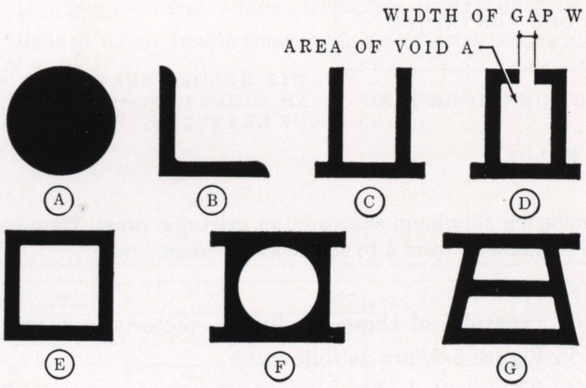


Figure 3-8: Extruded shapes:
A-C: Solid extruded shapes.
D: Semi-hollow extruded shape. Tongue ratio R = A_2/W is larger than 1½ (if smaller than 1½, shape is considered solid). Minimum producible gap width: 0.030-inch.
E-G: Hollow extruded shapes.

thickness. The length of the thin protruding legs should not exceed 10 times their thickness. Dimensional tolerances on such thin legs are hard to control because of variations in metal flow through the die.

5. In Shapes E and F, which show severe variations from thick to very thin cross-sections, straightness and flatness are hard to maintain. Waves tend to form in the thin end of Section E; a blunt end as shown by dotted lines would alleviate this condition. In Section F, a smaller difference in section thickness would facilitate flattening the thin web.
6. In multi-hole hollow shapes, adequate thickness between holes is necessary. In Section C, for instance, the center web should be increased to ⅛-inch.
7. Shape G, with a long narrow tongue flanked by a heavy mass of metal, is undesirable. The preferred design, which should be approached as closely as possible, is shown in H. Tongue width is increased, tongue depth reduced, the thick section is narrowed down, and a radius added at the tongue gap. The dotted line indicates the open position in which the leg will be extruded, to be closed by a rolling pass after extrusion.
8. In very thin shapes, such as Section L, a generous fillet radius helps to maintain straightness.
9. The metal flow of heavy unsymmetrical hollow shapes, such as Section N, where the void is near the edge of the section, is difficult to control. Extrudability is improved if a second void, as indicated in dotted lines, is added. The closer a hollow shape approaches uniform wall thickness, as illustrated by Sketch M, the more readily can it be extruded.

Weight and Dimensional Limits of Extruded Shapes: Minimum and maximum weights per foot are dependent on the limits of the extrusion ratio which is the ratio of cross-sectional area of the extrusion ingot to the cross-sectional area of the extruded shape. This ratio should not be greater than 45:1 and no less than 16:1, corresponding to minimum and maximum weights of 1 ounce or less, to 20 pounds. The maximum weight of 20 pounds corresponds to a cross-sectional area of 15 square inches.

The maximum length of an extruded section depends on the weight per foot of the section, and upon what the heat-treating and shipping facilities

can accommodate. See Table 3-1. While a 40-foot length is considered the maximum practical, it is possible to produce lengths up to 50 feet or more provided no heat treatment is required and the cross-sectional area is not too large.

Cross-sectional dimensions have to be kept within a circumscribed circle of approximately 23 inches in diameter, as commercially practical presses, at the present time, cannot handle larger dies. This limitation may be overcome in certain cases by the method indicated in the caption of Figure 3-10.

Thickness of the desired section is a factor determining whether extruding is feasible. Very thin sections are better furnished as continuous-roll-formed shapes. The minimum permissible thickness of an extruded section or of a part thereof is basically a function of

1. the width of the shape, measured in terms of the diameter of the smallest circumscribed circle around the shape. The wider the shape, the greater must be the minimum thickness.
2. the type of extrusion. Minimum thickness is greater for hollow shapes than for solid shapes (see Table 3-2).
3. the softness of the alloy. The softer the alloy, the thinner may be the section.

Fits and Assemblies of Mating Extruded Shapes: Shapes which cannot be extruded as a single section because of dimensional limitations or complexity of cross-section can be obtained by assembling mating extruded sections. Various possibilities are shown in Figures 3-11 to 3-16. Regular joints, peculiar to extruded shapes, are treated in detail in Section 4.9.

Advantages of extrusions can be listed as shown below:

—The extrusion process greatly simplifies design, inasmuch as the engineer has an exceptionally free hand in choosing the most suitable shape.

—It is a particularly useful process for meeting specific non-standard requirements.

—It is highly economical because of the relatively low cost of the dies.

—Since metal can be placed exactly where most useful, light weight coupled with high strength and easier handling, with lower transportation costs and less wear and tear result.

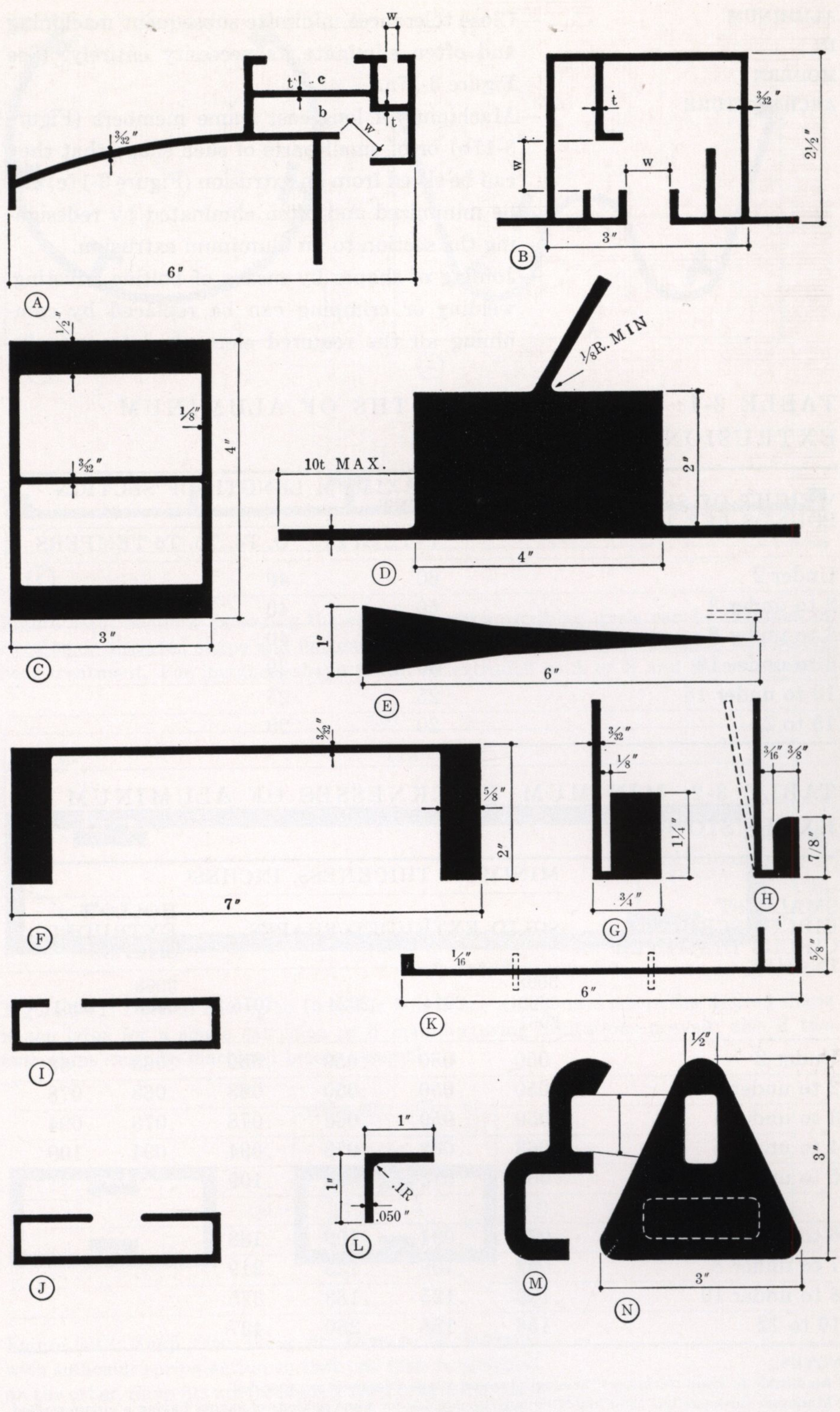


Figure 3-9: Examples of poor extrusion design. Shapes such as those shown here present certain difficult manufacturing problems and should be modified, if at all possible.

—Close tolerances minimize subsequent machining and often eliminate its necessity entirely. (See Figure 3-17a.)

—Machining of long cast frame members (Figure 3-17b) or of small parts of such shape that they can be sliced from an extrusion (Figure 3-17c) can be minimized and often eliminated by redesigning the section to an aluminum extrusion.

—Joining of shapes by means of bolting, riveting, welding or crimping can be replaced by combining all the required elements into one aluminum extrusion, thus reducing costs. (See Figures 3-17d-f).

—Where the required cross-sectional dimensions exceed the capacity of the largest presses, i.e., where they would extend beyond a circumscribed circle of 23 inches, it is possible to extrude them in circular or distorted shapes, as shown in Figure 3-10. After extrusion and before heat treating, these sections can be formed to the desired shape. This possibility affords a particular advantage where a great many joints would otherwise be necessary.

—Extrusions are straighter, dimensionally more accurate, and have a better surface finish than rolled shapes.

—Extrusions can be "tailored" more economically than roll-formed sheet sections, e.g., by adding ribs, lugs or pads. Greater stiffness and strength for equal weight can often be obtained simply by varying the cross-section (see Figure 3-17g).

—Extrusion facilitates the production of a great variety of ornamental shapes not obtainable by other methods except at greater expense.

TABLE 3-1: MAXIMUM LENGTHS OF ALUMINUM EXTRUSIONS

WEIGHT OF SECTION POUNDS PER LINEAL FOOT	MAXIMUM LENGTH OF SECTION FEET	
	F TEMPER	O, T4, T5, T6 TEMPERS
Under 2	60	40
2 to under 3	50	40
3 to under 6	40	40
6 to under 10	30	30
10 to under 15	25	25
15 to 25	20	20

TABLE 3-2: MINIMUM THICKNESSES OF ALUMINUM EXTRUSIONS

SMALLEST CIRCUMSCRIBING CIRCLE DIAMETER[2] INCHES	MINIMUM THICKNESS, INCHES[1]					
	SOLID EXTRUDED SHAPES				HOLLOW EXTRUDED SHAPES	
	3003 6063[4] 6061	2014[3]	2024	7075	3003 6063	6061
Under 2	.050	.050	.050	.050	.063	.063
2 to under 3	.050	.050	.050	.063	.063	.078
3 to under 4	.050	.050	.063	.078	.078	.094
4 to under 5	.063	.063	.078	.094	.094	.109
5 to under 6	.063	.078	.094	.109	....	....
6 to under 7	.078	.094	.109	.188	....	....
7 to under 8	.094	.109	.125	.219	....	....
8 to under 10	.109	.125	.188	.375	....	....
10 to 12	.156	.188	.250	.437	....	....

NOTES:
[1] Applicable to mean thickness if unequal plus and minus tolerances are specified.
[2] Minimum thickness less than indicated may be possible for some sections of shapes having a circumscribed circle diameter under 2″.
[3] Minimum thickness of 2014-T6 is 0.125″.
[4] Maximum thickness of 6063-T42 and 6063-T5 shapes is ½″.

3.3 CAST PRODUCTS AND THEIR PRODUCTION IN THE FOUNDRY

SAND CASTINGS: Molds made of sand are lowest in cost and permit greater flexibility in design changes. Labor costs are higher than for other castings. Sand castings are rougher in appearance and vary in quality. No close dimensional tolerances are obtainable with these castings. They are, therefore, mostly used for such applications as spandrel panels, wall facing panels for exteriors, window mullions, casings for concrete, posts for bridge railings and the like.

PERMANENT-MOLD CASTINGS: This method employs metal molds with a metal core. If a sand core is used, the casting is called a semi-permanent mold casting. Molten metal is poured into the mold under its own gravity pressure.

DIE CASTINGS differ from permanent-mold castings only in that the metal is forced into the die

cavity under pressure by means of a special casting machine.

Permanent-Mold and Die Castings Versus Sand Castings: The main advantages of permanent-mold and die castings over sand castings are higher strength, better surface appearance and closer dimensional tolerances resulting in increased accuracy and rendition of detail. Die castings have smoother surfaces compared to permanent-mold castings.

Permanent-mold and die castings are used for ornamental work requiring high accuracy and a smooth surface, whenever the quantity needed justifies the higher cost. Die castings, in particular, find application in small mass-production items such as handles, latches, and other door and window fittings, and the like.

Commercial dimensions of aluminum castings are usually limited to about a maximum size of 5 x 7 feet although lengths up to 10 feet are sometimes furnished. The minimum practical thickness of a casting that is 5-foot square is about 3⁄16-inch.

3.4 TEMPERING TREATMENTS

Pure aluminum is alloyed to provide added strength, to make it responsive to heat treatment, or to obtain other desired characteristics. Where a tempering treatment is applied, it may be either a heat treatment with subsequent quenching and aging, or a work-hardening (strain-hardening) process, or a combination of these treatments.

HEAT TREATMENTS: Whether or not an aluminum alloy will respond to heat treatment depends primarily on the alloy composition. In the molten state, certain alloying elements will be dissolved in the aluminum. In the course of solidification, some constituents will remain in a state of solution, others will precipitate. The latter may be either re-soluble or insoluble, or they may be a combination of both, depending on the composition of the alloy. The purpose of the heat treatment is to return certain soluble constituents into solution. The metal is brought to an elevated temperature and rapidly quenched in water to accomplish this.

Those alloys with a high degree o˙ solid solubility at an elevated temperature and limited solubility

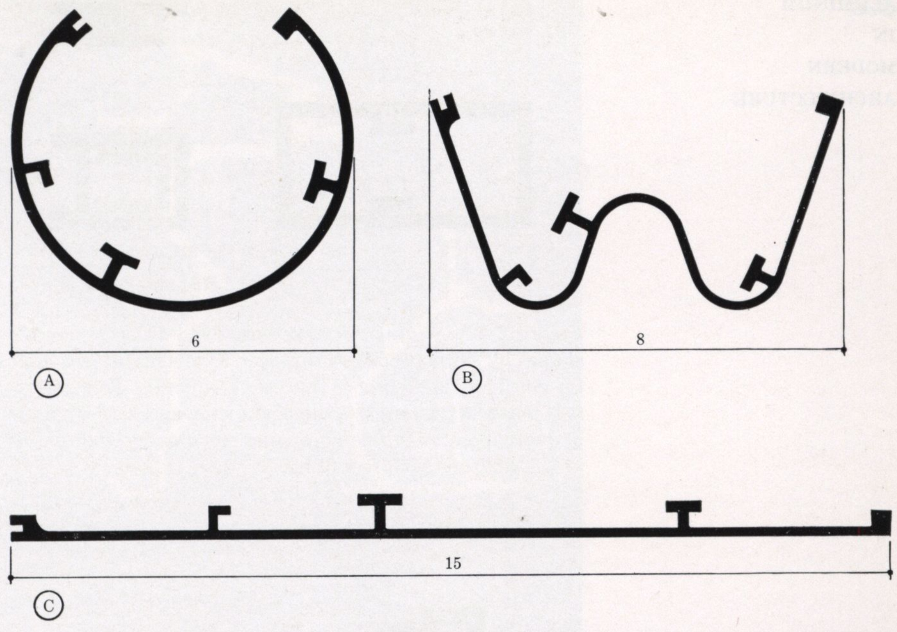


Figure 3-10: Sections exceeding the maximum circumscribing circle can be extruded in circular or distorted shape and flattened to the desired shape after extrusion and before heat treatment. For instance, shape C can be extruded as A or B and then flattened.

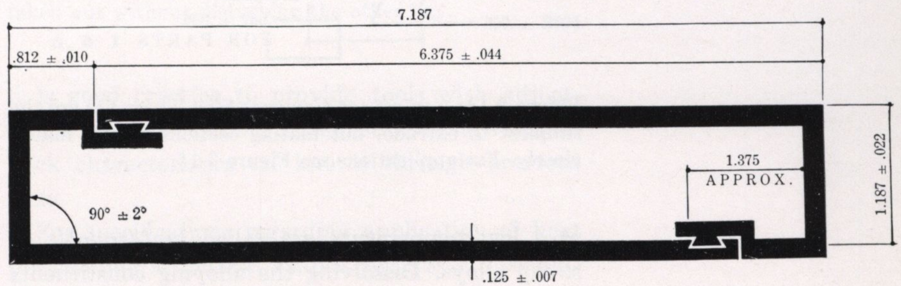


Figure 3-11: *Dovetail Fits* up to 10 feet in length are widely used where the desired shape is too large for a single extrusion or if manufacturing limitations prevail; also if two extrusions must be machined before assembly.

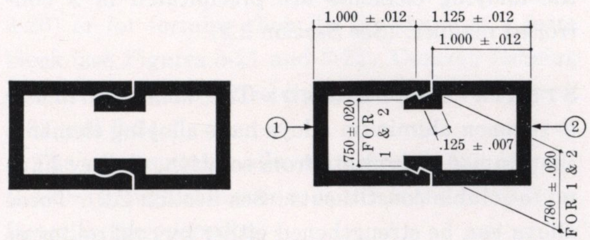


Figure 3-12: *Snap Fits*: These fits have to be designed with sufficient spring action so that one may be snapped on the other. Snap fits are frequently used in architectural work to conceal pipes, wiring and the like. The material to be enclosed is inserted after one part has been installed; then the cover part is snapped in place.

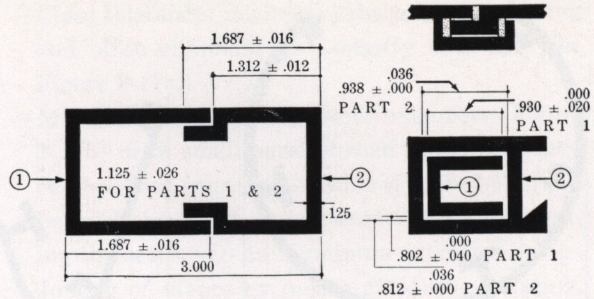


Figure 3-13: *Sliding Fits* are employed to form hollow shapes by sliding sections together. If assemblies are used for continual sliding or if they are frequently disengaged, it is necessary to apply a lubricant such as a zinc stearate or molybdenum sulfide compound to prevent tightening of the fit from surface galling.

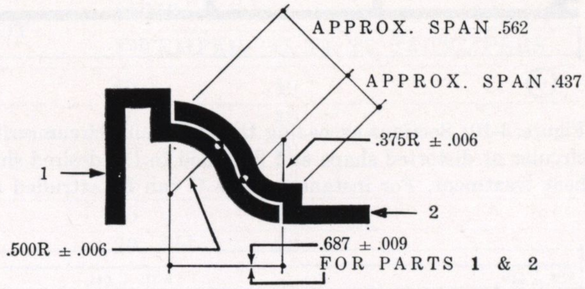


Figure 3-14: *Contact* (*or Contour*) *Fits:* These fits are the simplest to extrude, but mating sections should match closely. For applications see Figure 3-15.

at a low temperature are called *heat-treatable* or *strong* alloys. Dissolving the alloying constituents by heating is known as *solution heat treatment*. Maximum strength is obtained by subsequently employing precipitation or age hardening, in which the alloying elements are precipitated in a controlled manner. (See Section 2.2).

STRAIN HARDENING: The *non-heat-treatable* or *common* aluminum alloys have alloying elements that do not precipitate from solution, or they have no re-soluble constituents. (See Section 2.2). These alloys can be strengthened either by cold rolling or other plastic deformation. This process is called *strain hardening* and may be controlled in its degree by the amount of annealing.

ANNEALING: For maximum formability, the alloy should be in the soft temper . . . obtained by heating it to a temperature of 650–750°F and cooling slowly. This process is known as *annealing*. After the part has been annealed and formed, the desired strength, hardness, ductility and dimensional stability may be developed by tempering, described above.

3.5 FABRICATION

Fabrication includes forming and machining operations performed on aluminum mill products and castings, after they leave the mill or foundry.

FORMING: Aluminum is one of the most workable of all the common commercial metals. It can be fabricated readily into a variety of shapes by most any of the conventional methods.

Formability varies greatly with the aluminum alloy and temper (see Table 2-4). Unlike most other metals, aluminum does not have a definite yield point where plastic deformation will take place without the application of further stress. However, after a certain stress has been reached (varying with the alloy and temper), the metal deforms at an increasing rate. If the load is removed at this point, the metal will be found to have taken a permanent set. Yield strength values are always shown for a permanent set of 0.2 percent of the gauge length by the aluminum industry.

The spread between the ultimate tensile and yield strengths and the amount of elongation can be used for roughly determining the degree of formability; the greater the spread between tensile and yield and the higher the elongation, the greater the possible deformation without rupture.

Bending: The success of any bending operation depends primarily on the ability of the alloy to stretch on the outer surface which is under tension in the bend zone. The metal must also upset along the inner surface of the bend zone where it is under compression (see Figure 3-19A).

Temper and thickness must be given careful consideration (see Table 3-3), as they determine the minimum bend radius that can be employed without fracturing. Table 3–4 shows recommended inside radii on 90-degree cold bends for various alloys, tempers and thicknesses. Certain aluminum alloys

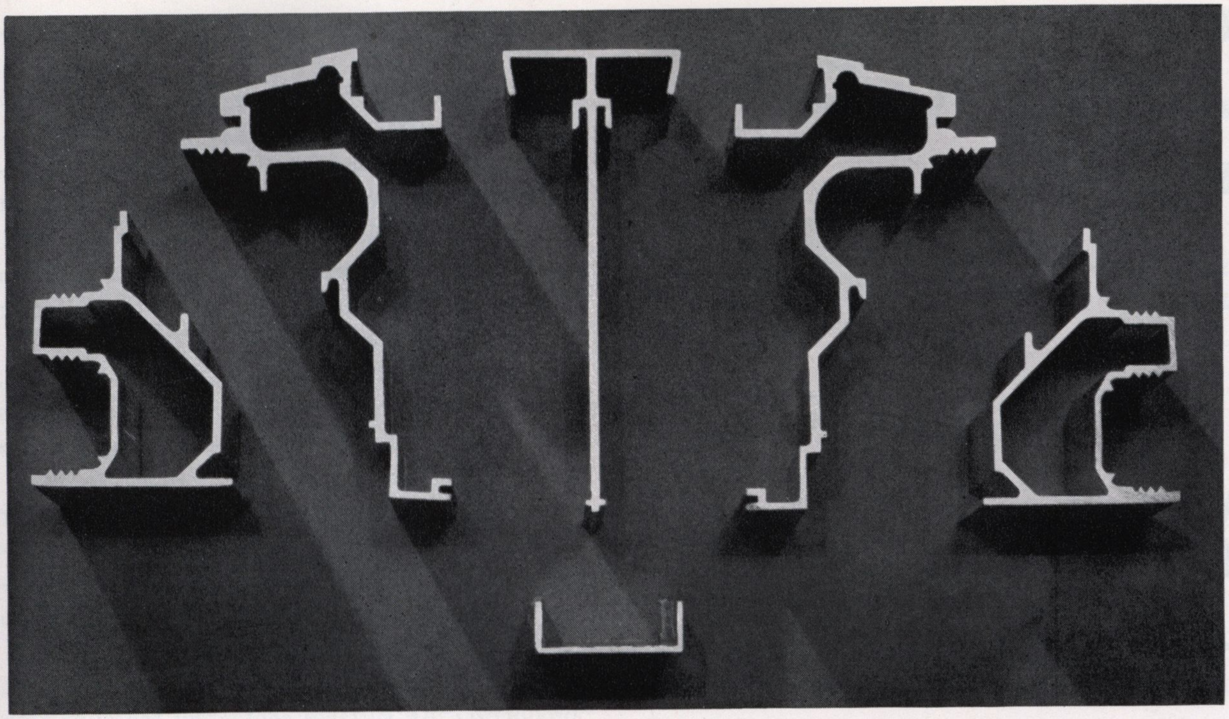


Figure 3-15: Example of contact fit: Mullion for monumental double-hung window (bottom) is assembled from several extrusions (top). For repair work, sections for one bay can be taken out without disturbing the other bay.

can be cold formed 90 degrees on a zero or sharp bend. Others must be formed on certain stipulated radii. The formula below may be used for calculating dimensional allowances, especially in case of several bends.

$L = 0.0175\ a\ (r + 0.4\ t)$

where

L = Length to allow, in inches

a = Total number of degrees bending occurs

r = Inside bend radius, in inches

t = Material thickness, in inches

Table 3-5 shows dimensional allowances for zero (90-degree) bending and for 180-degree bending.

A variety of bending and forming methods may be used with such conventional equipment as press brakes, bar folders, draw benches, dip rolls, tangent benders, all types of presses, roll formers and the like.

Because of the elastic recovery properties of aluminum (and most other metals), a small amount of spring-back may occur after forming. Since the exact amount of spring-back is difficult to compute, it is good practice to provide tools with adjustments for over-bending, unless the material's spring-back characteristics are known through previous tests.

For specifications regarding application of heat for bending structural shapes, see ASCE Proceedings (Appendix).

Stretch Forming and Contour Forming: Stretch forming is employed for stretching large sheets either for the purpose of flattening them (see Figure 3-20) or for forming them to the shape of a form block (see Figures 3-21 and 3-22). Contour forming not involving any stretching is shown in Figures 3-23 and 3-24.

The most suitable alloys for stretch forming are those with high elongation, as this is the controlling factor in the operation.

The advantage of stretch forming is that there is hardly any spring-back, as illustrated in Figure 3-19b.

Continuous Roll Forming: Roll formed shapes (see Figure 3-25) are produced by passing strip through

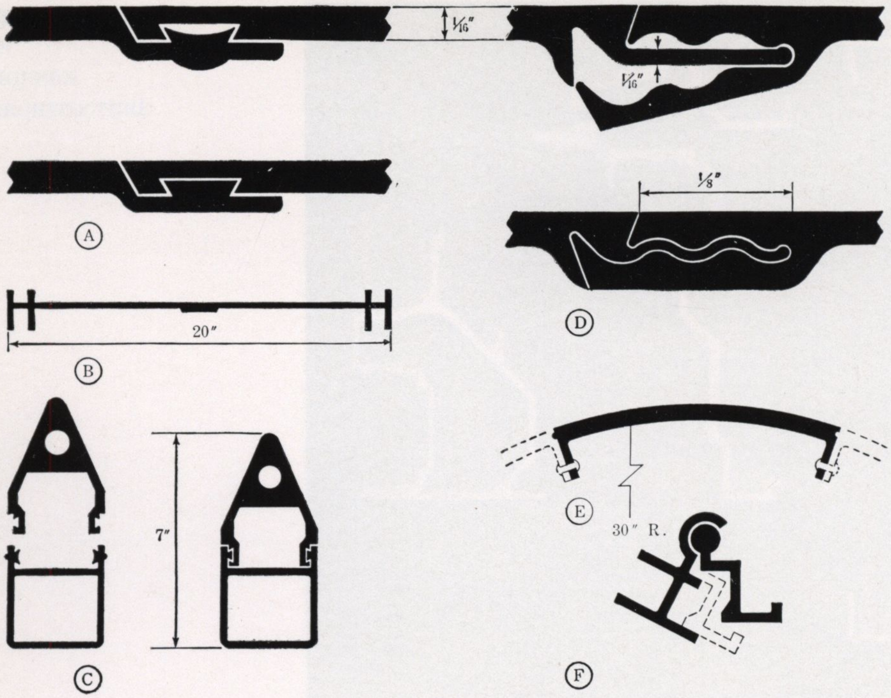


Figure 3-16: Special types of fits for parallel assemblies of extruded sections include a tongue-and-groove fit secured by a rolling pass (A), and a dovetail fit secured in the same manner (D). Sketches B and C show two examples of shapes which cannot be produced as integral sections because they exceed fabricating limits; they can, however, be designed as split-up sections and assembled after extrusion. Sketch E shows a cylinder of 60-inch diameter, built up from extruded segments. Sketch F shows a ball and socket type joint.

a series of roller dies in continuous-roll-forming machines (see Figures 3-26 and 3-27). Each successive pair of rolls cause the work to assume a cross-sectional shape more nearly approaching that desired. Thus only a small bend is made by any single pair of rolls. At the last pair of rolls, the final shape desired is produced. No straightening is required, since roll-formed products ordinarily are straight and free from distortion.

The advantages of the roll-forming process are as follows:

1. It is a fast, virtually automatic process, once the roll-forming machine is properly set up.
2. It affords precise control of metal thickness.
3. It reduces handling labor costs, and power.
4. Dimensions of shapes are practically unrestricted and are limited only by the dimensions of the material available.
5. Automatic arrangements can be made at the entrance end of the machine for piercing, notching and the like.

Continuous roll forming is done longitudinally only and is most economical in mass production. To avoid excessive strains, the forming is done gradually. This permits use of minimum bend radii about half of those required for press or brake bending.

Drawing: Aluminum and its alloys are drawn much in the same manner as steel and the other non-ferrous metals.

The non-heat-treatable alloys 1100, 3003, 5005, 5050 and 5052 are commonly used for drawn parts due to the greater degree of deformation possible with them before rupture.

For shallow draws, a single-action mechanical or hydraulic press is generally used; for deep or multiple draws, a double-action press. These latter have the advantage of permitting fine adjustment of the important blank-holding pressure.

Hardened tool-steel dies are used for large scale production. All surfaces contacting the aluminum are given a high polish to prevent scratching and scoring of the drawn part.

Radii of drawn parts range from four to eight times the metal thickness. Insufficient radii may result in a tensile fracture in the shell, while excessively large radii may cause wrinkling.

Hydraulic press rams equipped with rubber pads are normally used for the production of limited quantities. Male dies only are required inasmuch as the rubber acts as the female die.

Forming of various embossed designs, stretch and shrink flanges, flutes and the like can all be done with rubber dies.

Swaging aluminum tube can be accomplished in a rotary swaging machine. Aluminum swages exceptionally well, but caution must be employed when swaging alloys that work-harden fast and those that are of a temper restricting their workability (see Figure 3-28).

Bending of Aluminum Pipe and Tube: Forming aluminum pipe and tube can be accomplished by conventional methods used for other materials. Pipe made from an aluminum alloy having good ductility (stretch and elongation) with a reasonably high tensile strength is desirable for forming. Pipe

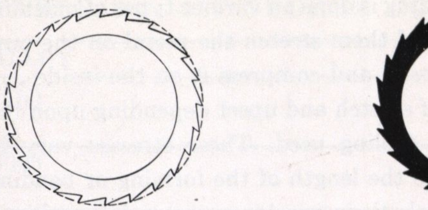


Figure 3-17a: Sections machined from bar stock or pipe can often be replaced by aluminum sections extruded to exact shape and size.

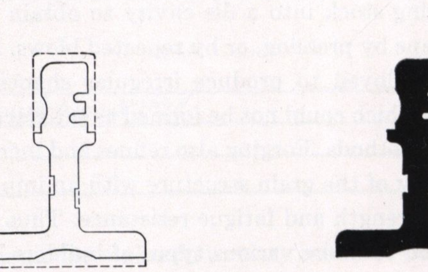


Figure 3-17b: Machining cost of long cast-iron frame members is minimized by redesigning the section to an aluminum extrusion.

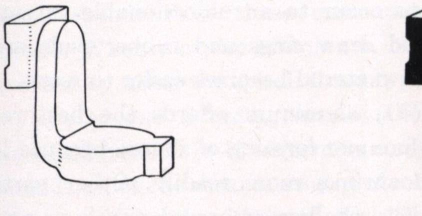


Figure 3-17c: Small castings, forgings or parts machined from bar stock may permit redesign to an extrusion if they may be sliced off the mother extrusion.

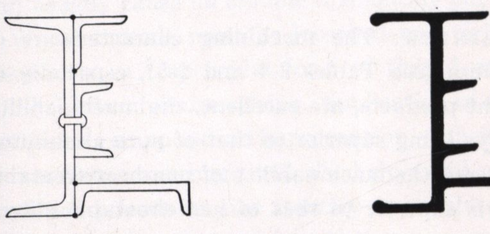


Figure 3-17d: Several rolled structural steel shapes can be combined into a single aluminum extrusion, thus eliminating joining costs and permitting closer tolerances.

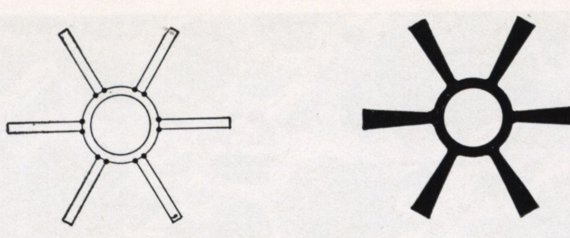


Figure 3-17e: Welded assemblies can often be redesigned to extrusions. Cost is reduced, while the strength and accuracy are improved.

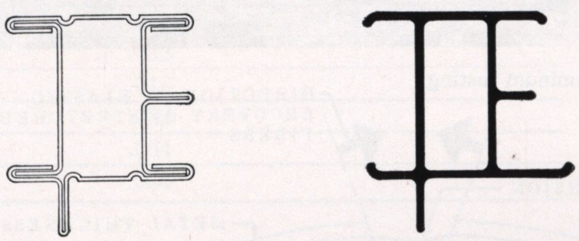


Figure 3-17f: Crimped tubular sections often permit redesign to extrusions with gain in stiffness and strength.

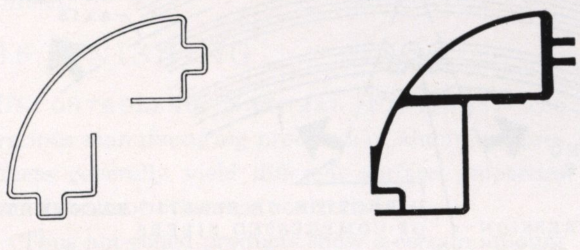


Figure 3-17g: Because extrusions permit changes of cross section, they can be "tailored" more readily than roll-formed sheet sections to meet specific design requirements. Bosses, ribs, flutes can be obtained easily.

with good elongation and low tensile strength, while the easiest to bend, will require careful tooling to avoid fracturing, flattening and collapse. Such collapse will occur if the ability of the alloy to absorb compressive stresses is exceeded.

The stretch and shrink properties of aluminum, as of other metals, are proportionately less for thin cross-sections than for heavier ones. This means that the minimum bend radius will increase with any decrease in wall thickness. Thin-wall tube is especially susceptible to fracturing or buckling. Extreme care must be used to confine the shape properly in the forming tools.

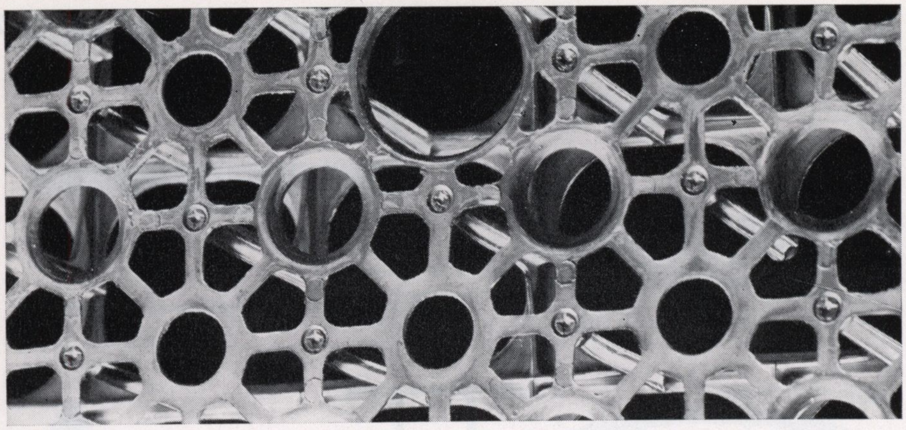


Figure 3-18: An example of aluminum casting.

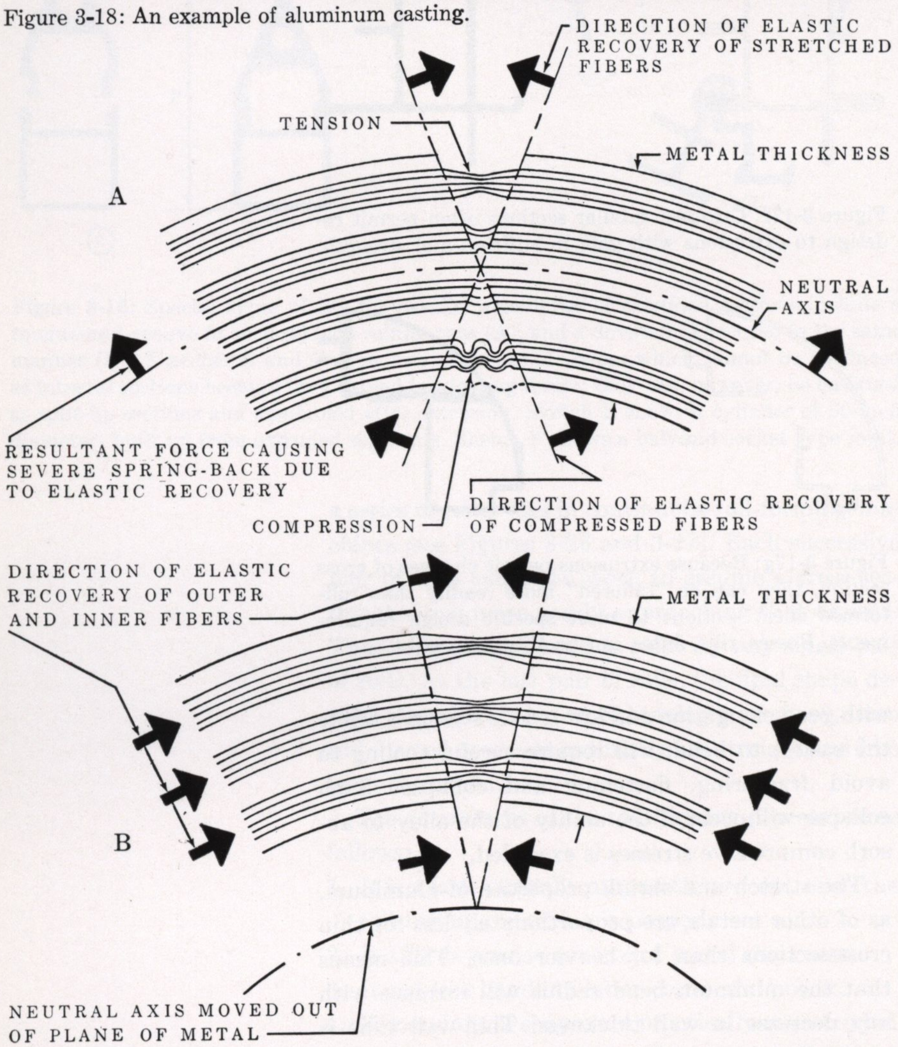


Figure 3-19: Upper diagram shows effect of bending a sheet of metal. It is the compression and tension forces locked in as shown here that cause "spring-back." Lower diagram shows how stretch forming eliminates spring-back as all metal fibers are now in tension.

Tube bending is done on various types of machine formers. All of them stretch the metal on the outside of the bend and compress it on the inside . . . the degree of stretch and upset depending upon the bender and tooling used. These stresses vary in proportion to the length of the forming or bending arc and reach their maximum intensity within a 90-degree arc. Forming over a longer arc does not create greater stresses.

Forging: Both press forging and drop-hammer forging have essentially the same effect; they force the forging stock into a die cavity to obtain a desired shape by pressing, or by repeated blows. Forging is employed to produce irregular shapes and contours which could not be formed as satisfactorily by other methods. Forging also refines and increases the density of the grain structure with an improvement in strength and fatigue resistance. Thus forging is used to make various types of builders hardware, where strength is of importance.

While the production rate is higher in drop-hammer forging, press forging has the advantages of lower die costs and fewer operations.

The drop hammer is seldom used to form thin material except parts where wrinkling and buckling are unlikely to occur to an objectionable extent. Where plywood draw rings and rubber pads are employed, thin material becomes easier to work.

Annealed (-O) aluminum affords the best results in drop-hammer forming of shapes because it stretches and shrinks more readily. Other parts such as channels, shallow embossed panels or any shallow irregular shape are often formed from metal of intermediate temper. Heat-treated parts can be formed satisfactorily by working immediately after quenching (see Figures 3-29 and 3-30).

MACHINING: The machining characteristics of aluminum (see Tables 2-4 and 2-5), especially of wrought products, are excellent, the machinability of alloys being superior to that of pure aluminum. In general, the machinability of non-heat-treatable alloys is superior to that of heat-treatable alloys. Both classes of alloys possess better machinability in the full-hard condition and offer less resistance to machining than any other common metal. Machin-

TABLE 3-3: 180-DEGREE COLD BENDING—METAL TO METAL

ALLOY	TEMPER	MAXIMUM THICKNESS—INCH
1100	–O to –H14	.250
	–H16	.016
3003	–O to –H12	.250
	–H14	.125
3004 and Alclad 3004	–O	.064
	–H32	.016
5050	–O	.250
	–H32	.125
	–H34	.064
5052	–O	.125
	–H32	.032
	–H34	.016
2024 and Alclad 2024	–O	.032
6061	–O	.064
2014	–O	.032

ing methods for aluminum vary but little from those employed for other metals, the most important difference being the selection of appropriate tools.

Sawing aluminum usually employs circular saws at high speeds, as they produce cleaner, straighter cuts than band saws.

Drilling operations require much higher rotational speeds than those customary for heavy metals. When *reaming* aluminum, chatter may be avoided by using the spiral-fluted types of reamers.

Tapping and threading employs thread lengths increased from 10 to 40 percent as compared to steel threads, since the shear strengths of some aluminum alloys are lower than those of steel. The higher percentage increase pertains, of course, to the softer aluminum alloys. Fine threads and those having a sharp V-contour should be avoided because of seizing tendencies. A rounded or trapezoidal thread will usually cause no trouble if smoothly cut.

Where threads must be loosened and tightened frequently, a trapezoidal form of thread contour will help to minimize seizing. Application of a good anti-seize compound or impregnation with it after an anodizing treatment will also help avoid seizing. Such compounds as zinc stearate or graphited oils and greases may be used for this purpose.

The tapping allowance on drilled holes should be slightly less on aluminum than on iron or steel, or an oversize tap should be used. This will help to compensate for the elastic deformation of the alloy during tapping and thereby avoid a tight-running thread.

3.6 FINISHING

UNCONTROLLED NATURAL FINISHES: The various manufacturing processes of aluminum products generally yield different surface properties which are not otherwise controlled.

Thus hot-rolled products show a certain amount of discoloration or darkening, while cold-finished products have a whiter, brighter surface. Extruded products have an intermediate appearance nearer that of cold-finished items and, in addition, show traces of longitudinal striations caused by the extrusion process.

Castings vary little in their surface appearance, except that die castings have the smoothest surface with permanent-mold castings the next best.

CONTROLLED NATURAL FINISHES: Natural finishes of cold-rolled sheet may be controlled by the degree of polishing given to the rollers of the rolling mill, or by other means as explained below:

Mill Finish refers to the surface of sheet given finishing passes through rolls that have not been highly polished. It may vary from bright to dull and

may not be free from stains or light films of rolling oil.

Mill Finish One Side Bright (or *One Side Bright Mill Finish*) refers to sheet, one side of which has a mill finish, the other side being somewhat brighter. Not a uniform finish.

Standard One Side Bright refers to sheet given a

TABLE 3-4: MINIMUM RECOMMENDED RADII FOR 90-DEGREE COLD BENDING OF ALUMINUM SHEET

These radii represent average values for forming on conventional equipment with tools of good design and condition. The minimum permissible radii are subject to several variables and can only be determined by actual forming under shop conditions.

ALLOY	TEMPER	THICKNESS OF SHEET—INCH .016	.025	.032	.040	.051	.064	.091	.125	.187	.250
		BEND RADII IN 32NDS OF AN INCH									
1100	–O	0	0	0	0	0	0	0	0	0	0
	–H12	0	0	0	0	0	0	0	0	3	6
	–H14	0	0	0	0	0	0	0	0	3	6
	–H16	0	0	0	0	1	2	3	4	8	16
	–H18	1	1	2	2	3	4	6	8	16	32
3003	–O	0	0	0	0	0	0	0	0	0	0
	–H12	0	0	0	0	0	0	0	0	3	6
	–H14	0	0	0	0	0	0	1	2	4	8
	–H16	0	0	1	2	2	3	5	6	12	24
	–H18	1	2	3	4	5	6	9	12	24	40
3004 & Alclad 3004	–O	0	0	0	0	0	0	0	0	2	4
	–H32	0	0	0	1	1	2	3	4	8	16
	–H34	1	1	1	2	2	3	5	6	12	24
	–H36	1	2	3	4	5	6	9	12	24	40
	–H38	2	3	4	5	7	8	12	16	32	48
5050	–O	0	0	0	0	0	0	0	0	0	0
	–H32	0	0	0	0	0	0	0	0	3	6
	–H34	0	0	0	0	0	0	1	2	4	8
	–H36	0	1	1	2	2	3	5	6	12	24
	–H38	1	2	3	4	5	6	9	12	24	40
5052	–O	0	0	0	0	0	0	0	0	0	0
	–H32	0	0	0	0	0	0	2	3	6	12
	–H34	0	0	0	1	1	2	3	4	8	16
	–H36	1	2	2	2	3	4	6	8	16	32
	–H38	1	2	3	4	5	6	9	12	24	40
2024 & Alclad 2024	–O	0	0	0	0	0	0	0	0	2	4
	–T3	1	3	4	5	7	8	12	16	32	48
6061	–O	0	0	0	0	0	0	0	0	2	4
	–T4	1	2	2	2	3	4	6	8	16	32
	–T6	1	2	2	2	3	4	6	8	16	32
7075 & Alclad 7075	–O	0	0	0	1	1	1	3	4	8	16
	–T6	2	4	6	8	10	12	18	24	40	64
2014	–O	0	0	0	0	0	0	0	0	2	4
	–T3	1	2	3	4	5	6	9	12	24	40
	–T6	2	4	6	8	10	12	18	24	40	64

much brighter finish approaching a uniform mirror finish on one side. The other side will have a mill finish or better.

Standard Bright Finish refers to sheet products having a mirror finish on both sides.

For many applications, natural finishes are completely adequate (see Table 3-6). The ever-present oxide film makes protective coatings unnecessary under ordinary conditions, and unless special decorative effects are to be obtained, the pleasing, natural appearance of aluminum requires no further finishing.

In addition to the aforementioned rolling finishes, there are other special mill-finishing operations for producing special purpose sheet. These include the following:

Alclads (clad aluminum sheet): This type of sheet is obtained by bonding to one or both sides of an alloy some other alloy which is to perform a specific function. The bonding is done by diffusing the core and the claddings into each other during hot rolling. If the primary purpose of the cladding is protection against corrosion, a layer of high-purity aluminum or a layer of an aluminum alloy of higher corrosion resistance and higher negative solution potential than the core (see Section 2.4) is employed. Alloys extensively used for cladding are of the 6000 and 7000 series.

In addition to the higher corrosion resistance of alclads, the cladding will also provide cathodic protection of the core at cut edges or at spots where the cladding has been removed.

Alclads are of special value for thin sheet requiring high resistance to perforations through corrosive action. They are often used for gutters, downspouts, flashings and the like.

Alclad products are ordinarily supplied in sheet and plate, sometimes in tube and wire; alclad extrusions have also been made on an experimental basis.

Brazing Sheet is a special type of alclad sheet usually of a 1100 or 3003 core with a high silicon alloy cladding that melts at a lower temperature than the core. Assemblies of parts made from this type of sheet can be brazed together by subjecting them to a temperature of about 1100°F which does not

TABLE 3-5:

FOR ZERO (90-DEGREE) BENDING

B & S GAUGE	ALLOWANCE FOR 90-DEGREE BENDS
Down to No. 23 (.023″)	None
No. 22 (.025″) to No. 20 (.032″) Incl.	1/32″
No. 19 (.036″) to No. 16 (.051″) Incl.	1/16″
No. 15 (.057″) to No. 14 (.064″) Incl.	3/32″
No. 13 (.072″) to No. 11 (.091″) Incl.	1/8″
No. 10 (.102″) to No. 8 (.128″) Incl.	3/16″
No. 7 (.144″) to No. 6 (.162″) Incl.	1/4″
No. 5 (.182″) to No. 4 (.204″) Incl.	9/32″
No. 3 (.229″) to No. 1 (.289″) Incl.	3/8″
5/16″	17/32″
3/8″	5/8″

Formula:—
Add all outside dimensions and subtract the number of bends × the allowance figure above. For 45-degree bends subtract one-half the allowance figure for each bend.

FOR 180-DEGREE BENDING

Formula:—
Add the outside dimensions and subtract one-half the metal thickness for each bend.

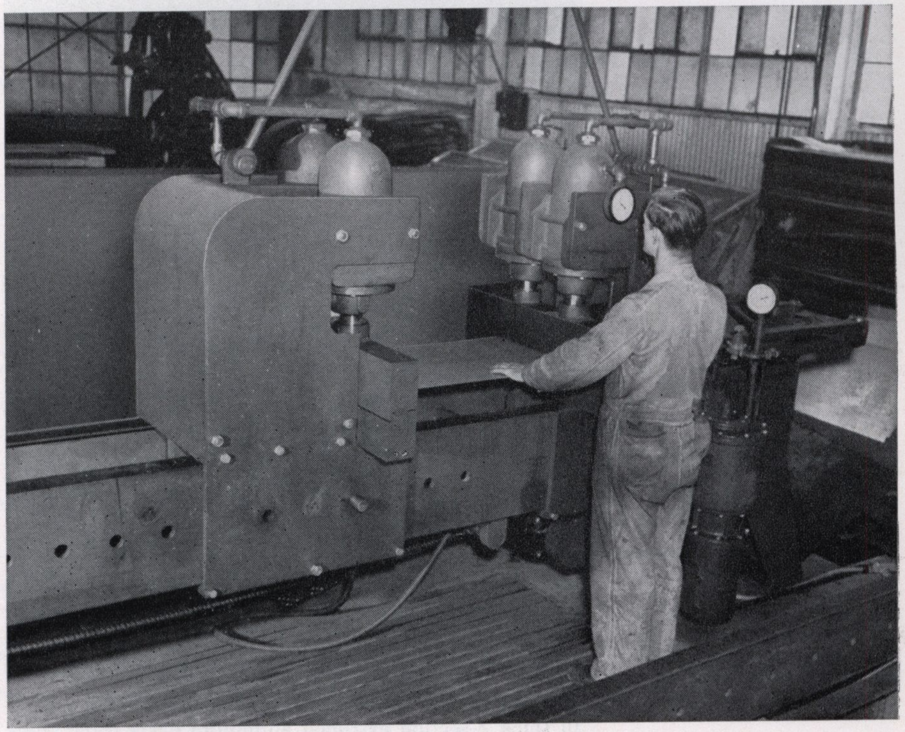


Figure 3-20: Embossed aluminum sheet being stretched to produce perfectly flat panels in plant of Rigid-Tex Corp., Buffalo, N. Y. Stretcher takes sheet up to 36 x 96 inches; 40-ton grip holds sheets; 7-ton force stretches them.

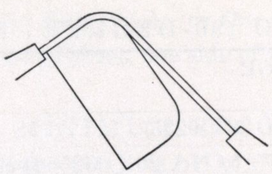


Figure 3-21: Stretch forming. Work is held at both ends; one end moved to wrap it around form block.

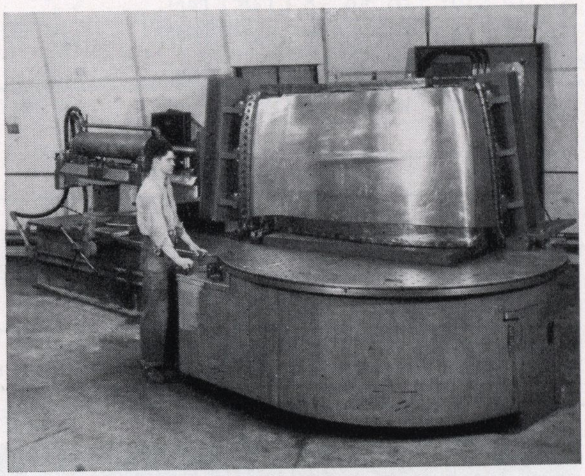


Figure 3-22: In this, as in most stretch formers, jaws grip the ends of the work while a hydraulic ram lifts the form die in the center, stretching the sheet metal to the three dimensional form desired.

Figure 3-23: Contour forming three-dimensional curves in thick Z-section extruded aluminum parts using compression forming method diagrammed in Figure 3-24. Hydraulic cylinder in rear operates forming roller while table revolves work about form block.

TABLE 3-6: SUGGESTED FINISHING

	REQUIREMENT
COLOR	Natural Aluminum (varies slightly with alloy and type of mill product)
	Special process colors
	Black
	Black for interiors
	Gray—various shades on architectural sheet
	slate
	greenish
	Green (on alloys)
	yellowish
	White (on commercially pure aluminum)
	Multi-tone metallic color
	Metallic colors (variety of colors available)
	Opaque colors (any color)
APPEARANCE	Natural finish on sheet
	Bright to dull
	Mirror finish one side
	Mirror finish both sides
	one or both sides for reflector sheet
	Bright surface (degree depends on process)
TEXTURE	Satin finish
	Sand blast (various degrees)
	Raised pattern
BASE FOR SUBSEQUENT TREATMENT	Base for paints
	Base for solder
	Base for brazing
	Base for electroplating
PROTECTION	Abrasion
	Corrosion
	Temporary protection

PROCESSES FOR SPECIFIC REQUIREMENTS

SUGGESTED FINISHES					
	PROCESS FINISHES				
NATURAL FINISHES	MECHANICAL	CHEMICAL	ELECTROLYTIC OXIDE (anodizing)	ELECTROPLATED	PAINTS, VITREOUS ENAMELS & OTHERS
Various types of mill finishes			Sulphuric acid process Oxalic acid process Sulfamic acid process Phosphoric acid process Boric acid process		
				Black nickel plating	
		Alkali arsenic staining			
			Sulphuric acid process		
		M.B.V. process			
			Chromic acid process		
		McCulloch			
		Alrok process			
		McCullogh			
		Pacz process			
			Colored anodic coating		
					Vitreous enamel paint, lacquer
Mill finish, mill finish one side bright					
Standard one side bright					
Standard bright finish					
Alcladding					
	Spin finish Buffing Mechanical polishing	Chemical polishing	Alzac, brytal, batelle processes		
	Belt polish, 180–220 emery Centerless belt polish, 180 emery (tube) Belt polish, 160–180 emery Belt polish, 120–140 emery Hand rubbed with steel wool Compound or brush back sander	Caustic etch + design etching	For colored background: Color anodizing after caustic etch or after design etching		
	Fine blast, 100 to 200 mesh Medium blast, 40 to 50 mesh Coarse blast, 16 to 20 mesh				
	Embossing Highlighting				
		Chromatizing treatments Phosphatizing treatments M.B.V. process Alrok process	Sulphuric acid process		
				Tin plating, copper plating brass plating	
Alcladding					
	Grinding Sandblasting	Zinc immersion process	Phosphoric acid treatment	Copper plating (for chromium finish) Nickel plating	
		Pacz process Annonizing process Brytal process	Sulphuric acid treatment Sulfamic acid treatment Phosphoric acid treatment Oxalic acid treatment	Chromium plating	
Alcladding		Annonizing process Brytal process McCulloch process Bonderite 170 Pacz process Zinc immersion process Protal process	Oxalic acid treatment Sulphuric acid treatment Sulfamic acid treatment Chromic acid treatment		Paint finishes
					Methacrylate type lacquer

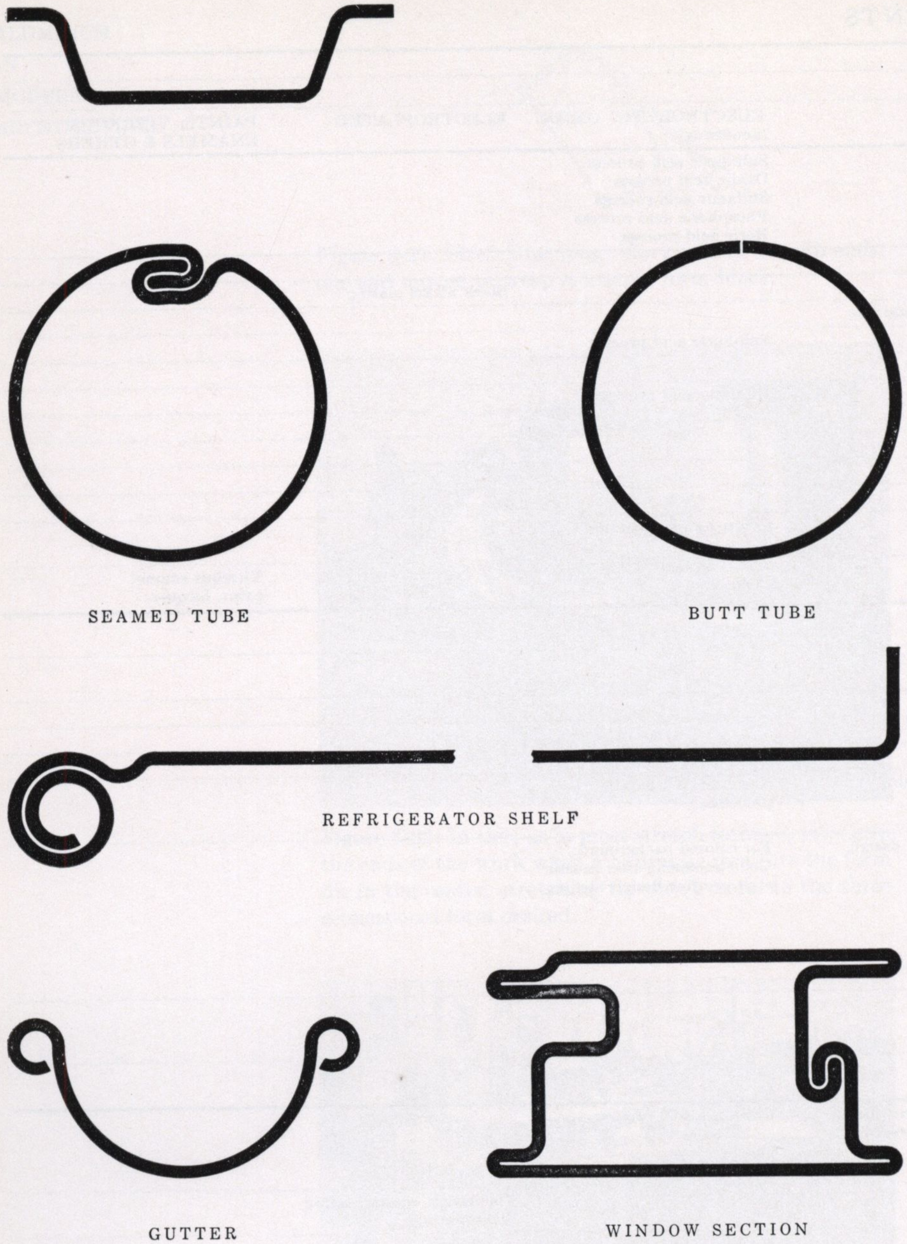


Figure 3-25: Typical aluminum shapes produced by continuous roll forming.

melt the core alloy but only the cladding, joining the surfaces. It is produced in flat sheet or coils and in tempers "-O" and "-H14" only.

Reflector Sheet is manufactured in two grades: No. 1 and No. 2. The former is used for diffuse reflectors which are normally etched and anodized. It contains a minimum aluminum purity of 99.3 percent. No. 2 grade is used for specular reflectors and is a composite material consisting of a 1100 or 3003 core (whichever is specified) and is clad on one or both sides with aluminum of minimum purity of 99.75 percent. Nominal thickness of the cladding is determined by the final thickness of the sheet. The clad side (in the case of one-side clad material) is used for the reflecting surface, the other side is usually marked to indicate that it is not to be used.

Flat Reflector Sheet is usually manufactured in thicknesses from .020 to .072-inch with width and length limits up to 54 inches and 180 inches, respectively. Coiled sheet comes in widths from 1 to 48 inches.

Embossed Sheet: This type of sheet is obtained by passing a commercial mill finished sheet through a pair of rolls with a matched design or between a design roll and a plain roll, if the embossed pattern is desired on one side only. Embossed surfaces hide wear and scratches and so retain their original fine appearance much longer than plain sheet. Too, they may eliminate the need for additional surface finishes, thus lowering the cost of the fabricated article. Embossed surfaces, at the same time, increase the stiffness of the sheet. Embossed sheet is usually available in thicknesses (before embossing) from .010 to .064-inch, in widths up to 60 inches, and lengths up to 220 inches, depending on thicknesses. Patterns include wood grain, leather grain, fluted, stucco, diamond, notched, ribbed, bark and pebble designs.

Architectural Sheet differs somewhat from the aforementioned types of sheet inasmuch as it is not supplied by the mill with the ultimate finish desired, but merely conditioned for it. It is made from an alloy of suitable composition and surface characteristics for the application of anodized finishes by the

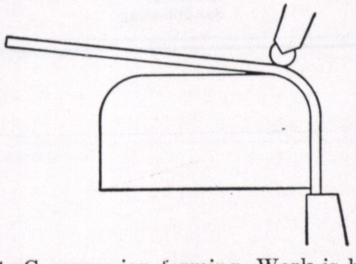


Figure 3-24: Compression forming. Work is held at one end; a roller used to wrap work around form block.

sulphuric acid process with or without pigments added.

Anodizing Architectural Sheet No. 5 will, for instance, yield a grayish decorative and protective coating. Architectural Sheets No. 1 and No. 4 result in natural surface finishes with the No. 4 sheet substantially darker than the No. 1 sheet.

Etching of certain types of architectural sheet prior to anodizing serves to eliminate streaks or other blemishes.

Architectural Sheet is ordinarily available flat, coiled or in circles.

PROCESS FINISHES are surface treatments applied by the fabricator and not in the mill or foundry. These finishes may have one or more of the following functions:

1. To change or improve the appearance of the surface for decorative purposes.
2. To improve its mechanical or chemical properties, such as abrasion or corrosion resistance.
3. To provide a base for subsequent surface treatment, such as painting.

Various process finishes for these requirements are recommended in Table 3-6; Table 3-7 shows approximate costs. Process finishes include mechanical finishes, chemical finishes, electrolytic oxide finishes, electroplated finishes, paints, vitreous enamels and others.

A prerequisite for successful application of any finish (except mechanical finishes) is a properly cleaned surface. Specifications by the ASCE relative to cleaning and treatment of metal surfaces to be painted for structural applications may be found in the Appendix.

Mechanical Finishes; Grinding: Dry grinding with a 25–50 grit abrasive cup wheel at a peripheral speed of 8,000 fpm is employed primarily for removing surface roughness from aluminum castings.

Buffing and Polishing: Buffing employs a fine abrasive such as Tripoli powder mixed with a grease binder, resulting in a highly lustrous surface. A roughing operation should precede the buffing, if deep scratches are present.

Polishing is done with finer abrasives than in buffing and with a very light pressure, using speeds

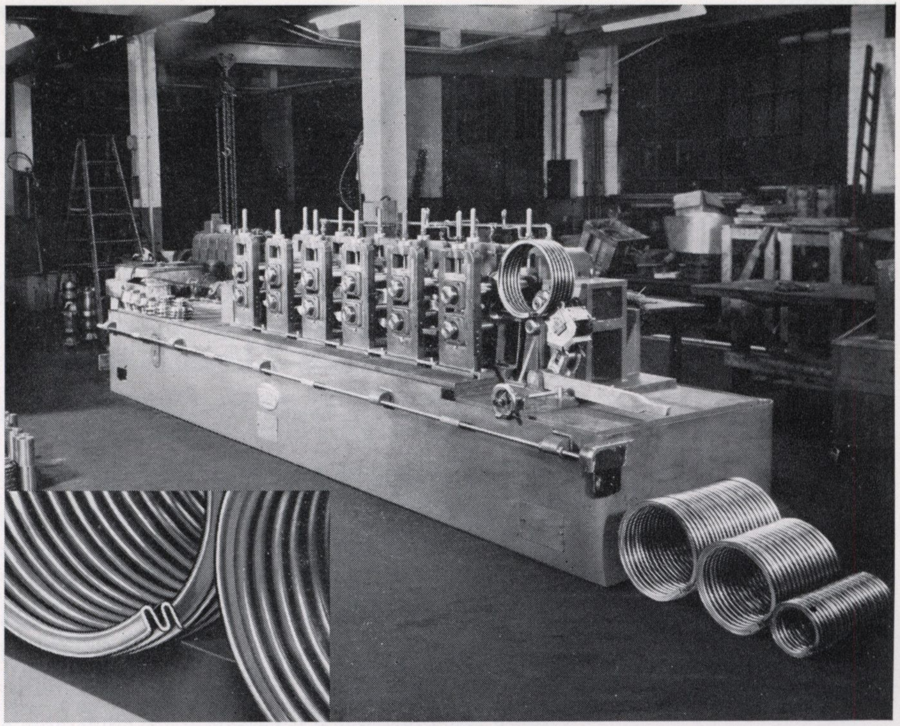


Figure 3-26: Continuous-roll-forming machine fitted with coiling device at exit end. Inset shows cross section through work produced. Note this setup employs six forming stations plus the coiler. Latter can be adjusted to produce diameter desired.

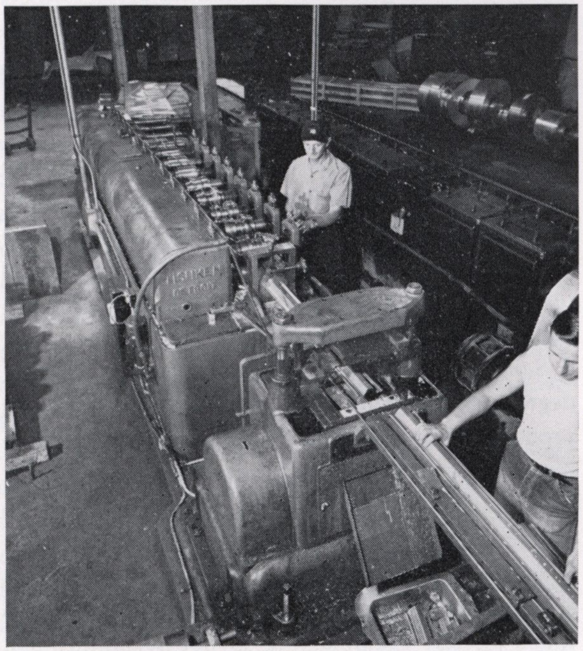


Figure 3-27: Eight-station continuous-roll-forming machine exits work through a sizing die and into a flying shear which automatically cuts it to required length. The machine is fed aluminum in the form of coiled strip.

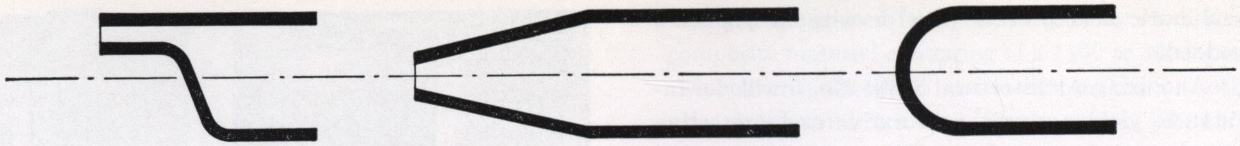


Figure 3-28: These are typical swaged parts.

around 8,000 sfpm. The resulting highly polished surfaces should be washed with soap and water from time to time to prevent dulling.

Scratchbrush Finishing employs power-driven rotating wire brushes to give the aluminum surfaces a coarse or smooth lined texture, depending on the size of the wire bristles in the brushes. Rough textures may be given a lacquer coat or may be anodized to avoid the collection of dust.

Satin Finishing is similar to the scratchbrush finish, except that the wires are of much smaller diameter. The same effect may be obtained by scratching the surface with very fine abrasives on a muslin or felt wheel. Both processes provide a soft, smooth sheen. Changing the angle of contact of the brush provides various effects.

Spin Finishing is achieved by pressing an oily abrasive cloth against the aluminum piece while it is revolved rapidly. Subsequent application of fine stainless steel wool and fine mesh emery gives a bright, silvery finish with a pleasing pattern of concentric circles.

Highlighting provides a two-tone effect suitable for relief surfaces, such as on architectural spandrels. The elevated areas are masked while the recessed areas are sandblasted. Then the masking is reversed and the elevated areas are given a highlight effect by painting or polishing them.

Sandblasting: Uniform matte surfaces in varying degrees of roughness and shades of gray can be produced economically by sandblasting, i.e., spraying sand or abrasives under controlled conditions. The resulting rough surfaces, however, should be protected by an oxide treatment or by painting.

Sandblasting may be used to prepare aluminum surfaces for electroplating, although zincating is much better. Sandblasting is not recommended. Too, sandblasting very thin sheets is not always practical, as it may distort sections of the sheet.

Chemical Finishes; Caustic Etch Finish is a decorative, silvery white finish, also known as "frosted finish." It is obtained by treating the work in caustic soda (sodium hydroxide). If partial etching is required, the entire surface is coated with an acid resist which is then removed from the areas to be etched. Since the etching removes the natural oxide film on the metal, it is necessary to provide a coating of clear lacquer or enamel to prevent fingerprinting or other subsequent markings.

Suitable proprietary etching compounds are Wyandotte Seneca Flakes or Wyandotte 1-2289-A2 (Wyandotte Chem. Corp.), Oakite #30 or Test Q (Oakite Products, Inc.), Detrex X (Detrex Corp.), Pennsalt A-15 or AE-18 (Penn. Salt Mfg. Co.), Cowles PC (Cowles Chemical Co.), Kelite Special Etch (Kelite Products, Inc.), Diversey #30 or Aluminux (The Diversey Corp.), Metex Cleaner #2 (MacDermid, Inc.), Dynamic Flakes (Turco Products, Inc.), Sprex (The DuBois Co.), Alkalume #4 (Northwest Chemical Co.), Enthone Cleaner E or Compound #139 (Enthone, Inc.), Cee-Bee Satin Etch (Cee-Bee Chem. Co., Inc.).

Design Etching is a chemical method for producing designs on aluminum by printing the design on the metal, and then dusting the ink-dampened areas with asphaltum powder. Remainder of surface not covered by the design is then etched.

A colored background can be obtained by applying a colored anodic or paint film before removing the asphaltum from the protected areas.

Conversion Films: Since the natural hard oxide film on aluminum provides a limited key for paints, it is best to treat the surface prior to applying a paint coat. These priming layers are known as conversion films and are obtained by either a chromatizing or phosphatizing treatment.

Chromatizing is used on aluminum parts to form thin, inert surface oxide films which serve to promote paint adhesion. The process consists of a 3 to 5-minute dip in a 5 to 10 percent chromic acid solu-

tion, maintained at a temperature of approximately 150°F. Parts are then rinsed in cold water and dried prior to painting.

Suitable proprietary compounds include Bonderite 710 (Parker Rust Proof Co.), Iridite 14 and 14-2 (Allied Research Products, Inc.), and Alodine 1000 and 1200 (American Chemical Paint Co.).

Phosphatizing forms a thin, inert phosphate coating on the metal produced by spraying or immersing the work for about 5 minutes in a 5-10 percent solution of phosphoric acid (75 percent) maintained at room temperature. Then they are rinsed in cold water and dried. Phosphatizing films are corrosion resistant and increase the bond obtained on subsequent paint films.

Phosphatizing is probably the simplest and least expensive chemical treating process available for preparing aluminum surfaces for painting. Suitable proprietary compounds include Bonderite 170 and D180 (Parker Rust Proof Co.), Alodine 100 (American Chemical Paint Co.), Lyfanite (Neilson Chemical Co.), Cee-Bee A-62 (Cee-Bee Chemical Co., Inc.), Kelite (Kelite Products, Inc.), and Alum-i-niel 979 (MacDermid, Inc.). Certain of the above may also be used as a final finish.

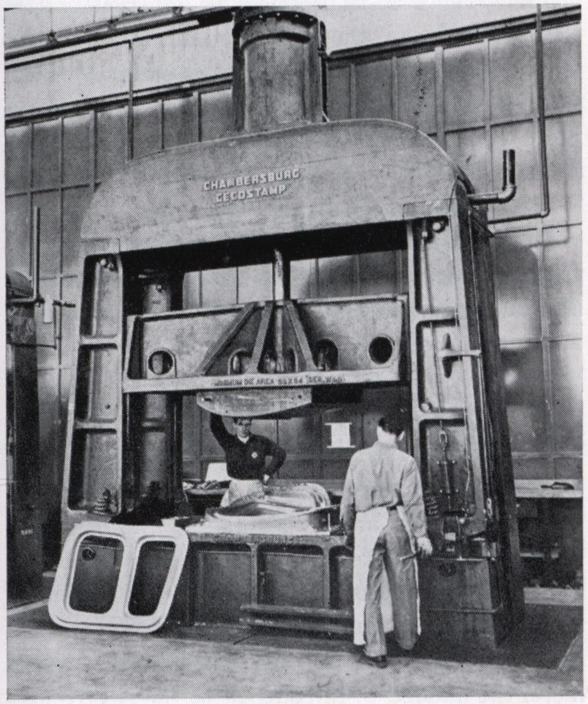


Figure 3-29: The air-powered Cecostamp represents an advance in drop-hammer equipment, as it offers better control of speed and power of the stroke. Here is a typical operation producing the aluminum part shown at left, at Curtiss-Wright Corp., St. Louis, Mo.

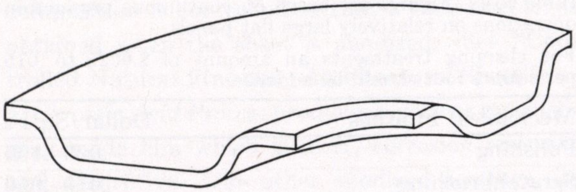


Figure 3-30: Typical part formed on a drop hammer.

Chemical Oxidizing: Chemical oxide films exhibit good corrosion and abrasion resistance and provide a good base for painting because of their porosity. They are more economical and easier to apply than anodic processes which also produce oxide films, but they are thinner and softer than anodic finishes. Although chemical oxide coatings may be dyed, anodic films are preferred if a superior color quality is desired. The two most widely used for chemical oxidizing are the Alrok and the Modified Bauer-Vogel processes.

Alrok Process specifies immersion of the work in a hot (about 150°F) solution of 2 percent sodium carbonate and 0.1 percent potassium dichromate for a period of about 20 minutes. The pores of the oxide film thus formed are sealed by subsequent immersion in a hot solution of 5 percent potassium dichromate, and the parts are then rinsed. The absorbed dichromate neutralizes any residual alkali in the coating and tends to increase its protective power. These oxide films vary in color, depending on the alloy treated, but are usually a yellowish-green after sealing in dichromate.

The Modified Bauer-Vogel Process (M.B.V. Treatment) is of considerable commercial importance in the foreign field for the production of a protective oxide film on aluminum alloys free of copper. The treatment involves immersion of the work in an aqueous solution of 5 percent sodium carbonate and 1.5 percent sodium dichromate at 195-212°F for 3–5 minutes, then rinsing in water. The surface film formed is a slate gray. It has fair adhesion and abrasion resistance. It makes a good base for paint-

TABLE 3-7: GUIDE FOR APPROXIMATING TYPICAL COSTS OF FINISHING ALUMINUM

Costs were estimated in 1951 and include labor and overhead, maintenance, depreciation and other applicable costs. Figures are based on continuous production operations on relatively large flat panels.

For cleaning treatments an amount of $.0025 to .015 per square foot should be added.

Mechanical Finishes	Dollar/Sq Ft
Polishing	.020–.100
Scratchbrushing	.010–.050
Satin Finishing	.010–.050
Chemical Treatments	
Caustic Etch	.010–.020
Alrok Process	.020–.040
Alodine Process	.015–.030
Bonderite 170 Process	.015–.030
Phosphatizing	.010–.020
Zincate Coating	.040–.080
Electrolytic Oxide Finishes	
Chromic Acid Process	.150–.300
Sulphuric Acid Process	.100–.250
Electropolishing	.200–.500
Coloring Anodic Coatings	.030–.060
Electroplated Finishes	
Copper Plating	.200–.400
Chromium Plating	.300–.500
Organic Finishes (Chemical Treatment and Paint)	.020–.080

ing and coloring and so is useful for this purpose.

Zinc Immersion Process: Aluminum may be coated with zinc by immersing the parts in a zincate bath at room temperature. The result is a very thin, firmly adherent coating of zinc on aluminum. This base is recommended wherever aluminum is to be electroplated. It is also known as *Zincating.*

Chemical Polishing: Producing mirror-bright surface finishes on aluminum by simple chemical processes has received increased attention in recent years. Usual procedure is to immerse the parts in a hot chemical solution, followed by subsequent rinsing. Depending upon the alloy and its mechanical preparation, reflectivity values up to 86 percent may be obtained.

In most cases these mirror-bright surfaces are not appreciably dulled by subsequent clear finishes produced by chemical oxidation or sulphuric acid anodizing processes.

Alkali Arsenic Staining may be employed to produce a black color on aluminum. The process involves immersion in a solution of sodium chloride and then in arsenous oxide, hydrochloric acid and ferrous sulphate. Aluminum parts so treated are for interior use.

Anonizing is a proprietary process developed by the Colonial Alloys Co., Philadelphia. It produces a substantially colorless oxide coating with good corrosion resistance and increased abrasion resistance. The appearance of the film is somewhat similar to that produced by the sulphuric acid anodizing process.

The Jirotka Process results in a film of good adherence and is used as a base for painting and electroplating. The surface obtained is of aluminum oxide with heavy-metal particles embedded in it, as the processing solution contains a number of heavy-metal salts.

The Protal Process produces an adherent protective oxide film on the metal.

The Pacz Process is essentially an etching process in which the solution dissolves aluminum and exposes those alloy constituents that are not attacked. This results in a variation of color tone. The film produced is abrasion resistant.

The McCulloch Process results in a white film on commercially pure aluminum and a greenish-white film on aluminum alloys. Both films are adherent and protective.

ELECTROLYTIC OXIDE FINISHES (ANODIZING): Electrolytic oxide coatings are readily applied to aluminum alloys and are widely employed because of their many outstanding physical and chemical properties. Oxide finishes are obtained by building up the natural oxide film by the anodizing process, using an oxygen-yielding electrolyte such as sulphuric, chromic or other acid and making the metal the anode . . . in contrast to the electroplating process where the metal is the cathode.

The anodic film, which is integral with the aluminum itself, consists essentially of amorphous aluminum oxide but may contain other substances from

the electrolyte. The film is very hard and durable. It has high dielectric strength with excellent abrasion and corrosion resistance.

Anodic coatings may be transparent or of varying degrees of silver, gray or brown, depending on a number of variables as explained in the following. They are highly absorptive for dyes and paints. A boiling water treatment will convert the oxide into the monohydrate, sealing the pores and thus preventing further absorption. A number of electrolytic oxide processes are described below. The sulphuric acid process is the most common.

Sulphuric Acid Process: Anodizing with a sulphuric acid electrolyte is part of the Alumilite process. It usually employs direct current, but alternating current may be used if desired. In general, the oxide films obtained in a sulphuric acid electrolyte are very corrosion and abrasion resistant, are highly absorptive, inert and heat resistant. Oxide films are commercially made in a sulphuric acid electrolyte to have a thickness ranging from 0.0001 to 0.001-inch. Minimum film thicknesses of 0.0004-inch should be specified for interior use and exterior use with maintenance, and 0.0007-inch for exterior use without maintenance, for both wrought and cast products.

Do not use this or any other anodizing process (except chromic) where there is any probability of retaining acid by capillary action in a closed space such as a lapped joint. This is important since any acid so retained will cause subsequent deterioration of the aluminum by contact.

The sulphuric acid process is the most economical. The coating will vary from a clear, transparent film to one that is opaque or translucent depending upon alloy, timing and solution concentrations. Coatings become more opaque as alloy constituents increase. The brightest and clearest surfaces are obtained with alloys containing magnesium (5000 series), and magnesium and silicon (6000 series) as major elements. Alloys with manganese as the major element (3000 series) show a *yellowish color*, while alloys of the 5000 series with large amounts of magnesium have a *brownish-gray appearance*. Copper-containing alloys yield rather *dark coatings*.

Silicon is not noticeably dissolved by the anodic process and thus remains in the coating, giving it a *gun metal gray* color. Since most aluminum castings contain silicon, they appear rather dark when anodized.

In the production of architectural sheet, the alloy composition is controlled so that a desired color is obtained when the sheet is anodized. (See "Controlled Natural Finishes—Architectural Sheet").

Chromic Acid Process produces a gray or greenish-gray oxide film which is inert, corrosion resistant and absorptive. Like other anodized coatings, its thickness depends on current density and time of treatment; the average thickness is about 0.00005-inch. It may subsequently be colored in dye baths. This process is particularly suitable for assembled parts, since this acid may be trapped in joints with little or no deleterious effect.

Oxalic Acid Treatment: Films obtained by this method are of moderate hardness and abrasion resistance. Their corrosion resistance is good. Average thickness is about 0.0001-inch.

Sulfamic Acid Treatment produces films similar to those formed in oxalic and sulphuric acid electrolytes. They are transparent and porous, abrasion and corrosion resistant, and have good dye absorptive qualities, good heat radiating power and good electrical resistance.

Phosphoric Acid Treatment produces a hard and durable oxide film that is a good base for electroplated coats where a base smoother than that obtainable by zincating is required.

Boric Acid Treatment affords a hard, impervious, non-absorptive film. Its exceptionally high electric resistance makes this coating preferred where such insulating properties are desired.

Colored Anodic Coatings: Anodized films are porous and thus provide an excellent absorptive medium for water-soluble dyestuffs and pigments. The *metallic luster of colored anodic films has great decorative attraction.* After coloring, sealing in boiling water will close the pores of the film, making it stain and corrosion resistant. Where a high degree of corrosion resistance is required, special corrosion inhibitors may be incorporated in the coating.

There are three methods for dyeing an anodic film:

1. The work is immersed in an organic dye bath, thus absorbing the color.
2. The oxide film is treated successively with solutions which react with one another on the film to form insoluble colored compounds. A few of these solutions are nickel-acetate treated with ammonium sulphide to produce *black* films, zinc acetate treated with potassium dichromate to produce *yellow* films, and potassium ferrocyanide treated with ferric chloride to produce *blue* films.
3. Colored oxide films may also be produced directly in the anodizing bath by acid combinations and additive agents. For example, chromic and oxalic acids produce *varying shades of brown;* sulfamic acid and sodium borate produce *silvery* films. The time, temperature, current density, voltage and electrolyte used, as well as the aluminum alloy treated, have a direct bearing on the color obtained.

Electropolishing: High purity aluminum may be treated by electropolishing to obtain a light reflectivity of about 85 percent. Electrolytic buffers remove impurities from the aluminum surface and level off minute elevations. The very thin oxide film produced may be reinforced by subsequent anodizing in sulphuric or other acids to obtain a clear, hard coating resistant to corrosion and high temperatures.

The work is made the anode and metal is removed selectively by the phenomenon of anodic polarization. The depressions are made anodically passive and the elevations anodically active. This causes the rate of dissolution of elevations to be greater than that of depressions. The grains of the metal are not distorted as when mechanical buffing is employed, and a brilliant, highly polished surface is obtained.

The Alzak, Brytal and Battelle processes are typical commercial applications of electropolishing. These processes are used extensively in making aluminum lighting reflectors.

Alzak Process employs an anodic treatment in a 2.5 percent solution of fluoboric acid, producing surfaces which reflect some 85 percent of the incident light.

Brytal Process entails treating the work anodically in an alkaline solution. The reflectivity obtained is about 85 percent. The film possesses good corrosion and abrasion resistance.

Battelle Process was developed by the Battelle Memorial Institute. It yields high reflectivity on suitable aluminum sheet. The cleaned and rinsed parts are immersed in a bath of 40 percent sulphuric acid and 60 percent phosphoric acid. About 0.0002-inch of metal may be removed during this treatment.

Electropolished reflecting surfaces are usually given a final oxidizing treatment to provide protection to the highly finished surface. Final reflectivity will depend upon the purity of the aluminum, the thickness of the oxide film, and the particular procedure employed. The film is usually sealed by immersion in boiling water. In service, cleaning with mild soap and water at intervals will remove accumulations of grime and will restore the original high reflectivity.

Electroplated Finishes are employed primarily as a means of enhancing the decorative effect. They may be applied on aluminum as on other metals if the metal is first coated by the zinc immersion process (zincating). Chromium and copper plates are the most common and easiest to apply.

Chromium Plating: Chromium is readily plated on aluminum either after zincating, or after copper, brass or nickel plating. Lustrous chrome plate is easy to obtain by plating over buffed copper, brass or nickel plates on aluminum, and then buffing the chromium to the polish desired. Chromium plates are generally applied for the decorative effect obtained and for resistance to abrasion.

The plating thickness varies from 0.00002-inch for decorative purposes to 0.0005-inch or thicker for wear resistance. Patents pertaining to chromium plating are held by United Chromium, Inc.

Copper Plating aluminum may be done after anodizing in phosphoric acid. The thickness of plating varies from 0.0005 to 0.001-inch, depending on the time in the solution. Copper may also be electrodeposited by first precleaning and then zincating the aluminum. The thickness obtained varies from 0.0005-inch for a color coat to 0.002-inch for a buffing coat, depending on immersion time.

Copper plates on aluminum are generally used where soldering operations are required, for certain electrical requirements and for decorative items.

Silver Plating decreases electrical resistance and is sometimes used for bus bar connections.

Tin and Brass Plates are especially good as a base for soldering.

Zinc and Cadmium Plates provide corrosion protection.

Chemically treated *nickel plates* yield a black decorative finish.

Vitreous Enamels in various colors may be applied to aluminum to obtain a hard, abrasion and heat resistant finish. These materials are complex glasses prepared by melting and then pouring the molten material into water. This shatters the glass into small particles called vitreous enamel frit. Many types of frit are produced but, chemically speaking, they are essentially lead borosilicates.

The aluminum is first freed of grease, then given one coat of ground enamel and air dried. This is followed by two coats of white or one or two coats of colored enamel applied by spraying or dipping. The optimum coating thickness is about 0.006-inch for two or more coats, but the coating thickness may vary from 0.002 to 0.009-inch.

Vitreous enamels are fused at fairly high temperatures, so the metal may soften and distort if thin gauges are held at heat for too long a period. Proper support during firing thus becomes important. The high temperatures employed will reduce the strength of the metal due to the annealing effect.

Paint and Other Finishes: Paint coatings may be desirable for decorative purposes or may be employed for added protection where aluminum is exposed to severely corrosive conditions . . . as in the presence of alkaline or acidic vapors, for instance. Application methods are basically the same as those for other metals.

Particular attention should be given to pretreating the aluminum surface to assure best adhesion. The Alrok, Bonderite, Alodine or Phosphatizing processes previously discussed are all satisfactory pretreatments.

Anodizing affords the best paint base but may be costly for some applications. Etching is an inexpensive method of providing an excellent key for paint. Lead pigmented primers should be avoided.

The selection of the final paint, lacquer or enamel coating should be made in accordance with service requirements and cost considerations.

For rough surfaces (produced by mechanical finishing processes), a coat of clear lacquer will prevent the collection of dust. While more economical, no paint or lacquer finish is as abrasion and corrosion resistant as an anodized surface.

Bituminous paints, also known as japans, usually contain asphalt and are employed to protect the metal under highly corrosive conditions, such as when embedded in soil or concrete, or immersed in salt water.

Specifications by the ASCE relative to painting of structures are included in the Appendix to Chapter 7 in the back of this book.

Miscellaneous other finishes which, however, are of limited application, include the following:

Luminous Paints should be applied over a white primer which is free of lead, manganese or cobalt. In outdoor applications these paints last about 2 years, but may be made to last longer by applying a clear paint vehicle as a top coat. Indoors, their service life extends over a long period of time.

Photographic Finishes may be produced on pure aluminum sheets which show no streaks or grains after clear anodizing. A light-sensitive substance is deposited in the pores of this film. Such plates may be used for negative or positive photo reproduction. After developing, the photographs are sealed in the surface by immersion in boiling water or coated with a clear lacquer.

The Silk Screen Process is applicable to bare as well as anodized aluminum and is used to reproduce name plates, display panels and the like.

Strippable Protective Coatings: Strip coatings are not of a permanent nature, although they should be weatherproof and temperature-proof. The most common ones are transparent lacquers of the methacrylate type. The purpose of these coatings is to protect the metal against staining during construction as it is always in danger of having mortar or other materials splashed upon it. Two coats of the

TABLE 3-8: SUITABILITY OF SOME FINISHING PROCESSES FOR CAST ALUMINUM ALLOYS

ALLOY DESIGNATION	TYPE OF CASTING	FINISHING PROCESS POLISHING	ELECTRO-PLATING	CHEM. OXIDE COATING (PROTECTION)	ANODIZING (APPEARANCE)
43	Sand C.	E	B	B	E
43	Perm. Mold C.	D	B	B	D
43	Die C.	D	B	C	D
214	Sand C.	A	E	A	A
B 214	Sand C.	B	D	A	B
F 214	Sand C.	B	D	A	A
A 214	Perm. Mold C.	A	E	A	A
B 214	Perm. Mold C.	A	E	A	B
C 214	Die C.	A	D	A	B
356	Sand C.	E	B	B	D
356	Perm. Mold C.	C	A	B	D

protective film with a total minimum thickness of 0.0006-inch should be applied. An air hose will provide quick removal.

Suitability of Finishes for Wrought and Cast Alloys: Wrought alloys take virtually all finishes without difficulty. The relative ratings for the suitability of some finishing processes on cast alloys are shown in Table 3-8. An "A" rating is best, "B" is next and so on.

Column 5 (Chemical Oxide Coating) shows ratings with respect to protective value. These coatings have a more or less metallic and often slightly colored appearance. It is seen that chemical oxide coatings provide good to excellent protection, although anodic finishes are generally more protective. Chemical finishes are less costly than anodic finishes and may often be adequate.

Column 6 (Anodizing) shows ratings with respect to appearance. In the absence of actual samples, which should be requested from the manufacturer, this information is a guide whenever anodizing is desired and when appearance is also of importance.

Maintenance of Surface Finishes: For plain and anodized surfaces a thorough cleaning with water, using soap or a wetting agent, will often suffice. If a stronger cleansing action is required, the use of a fine pumice powder or very fine stainless steel wool is recommended.

If a sterilizing sodium carbonate solution is desired, it is necessary to inhibit the alkaline effect by adding 5 parts of sodium silicate to 100 parts of sodium carbonate. Metal polish may be used for polished surfaces, but is not recommended for plain or anodized surfaces.

When repainting surfaces, the application of solvent stripping agents is satisfactory, provided they are not alkaline. In touching up spots that show metal, a primer should be applied first.

BIBLIOGRAPHY

THE ALUMINUM DATA BOOK by Reynolds Metals Company—1954.

ALCOA ALUMINUM AND ITS ALLOYS by Aluminum Company of America—1950.

KAISER ALUMINUM SHEET AND PLATE PRODUCT INFORMATION by Kaiser Aluminum & Chemical Sales, Inc.—1953.

HANDBOOK OF ALUMINUM ALLOYS by Aluminum Company of Canada—1951.

NOMENCLATURE: A GLOSSARY OF TERMS FOR ALUMINUM SHEET & PLATE AND ALUMINUM EXTRUDED AND TUBULAR PRODUCTS by The Aluminum Association—April 1952.

REYNOLDS ALUMINUM MILL PRODUCTS CATALOG by Reynolds Metals Company—Current Issue.

ALCOA ALUMINUM ALLOYS AND MILL PRODUCTS by Aluminum Company of America—Current Issue.

DESIGNING WITH ALUMINUM EXTRUSIONS by Reynolds Metals Company—1954.

COLD EXTRUSION—PRIMED FOR MASS PRODUCTION by R. H. Eshelman—The Tool Engineer, Sept. 1954—pp. 77-86.

ALUMINUM HEAT TREATING by Reynolds Metals Company—1954.

HEAT-TREATING OF ALUMINUM by E. S. Bunn—Industrial Heating, February 1954—pp. 236/48, 406/10.

THE HEAT TREATMENT OF ALUMINUM ALLOYS by W. E. Sicha, C. F. Nagel, Jr., and P. V. Faragher—Metals Handbook (American Society for Metals), 1948—pp. 775/77.

THERMAL TREATMENTS OF ALUMINUM ALLOYS by E. H. Dix, Jr.—Physical Metallurgy of Aluminum Alloys (American Society for Metals), 1949—pp. 200/40.

EFFECT OF IRON & SILICON ON AGE HARDENING OF THE HIGH PURITY Al-Cu ALLOY by M. Sumitomo—Chem. Abstr. 48, June 10, 1954—pp. 6355/56.

ALUMINUM FORMING by Reynolds Metals Company—1952.

FORMING AND BENDING by Kaiser Aluminum & Chemical Sales, Inc.

FORMING OF ALUMINUM by E. V. Sharpnack—Metal Progress, June 1953—pp. 166, 168, 170.

THE FORMING OF ALUMINUM SHEET by H. Hinxman—Sheet Metal Ind. 31, July 1954—pp. 557/61.

THE HOT-WORKING OF LIGHT METALS by F. Plattner—Zeitschr. fuer Metallkunde 45, May 1954—pp. 253/56.

HOW TO BEND ALUMINUM TUBE AND BAR by J. M. Adle—Am. Machinist 98, May 24, 1954—pp. 137/44.

BENDING ALUMINUM TUBING by J. E. Hawking—Tool Engineer 32, June 54—pp. 59-60.

DROP HAMMER FORMING OF ALUMINUM SHEET by H. Hinxman—Steel Processing, Aug. 1954—pp. 515/18.

ALUMINUM COLD FORGINGS by R. A. Quadt—Machine Design 26, June 1954—pp. 156/60.

MACHINING ALUMINUM ALLOYS by Reynolds Metals Company—1952.

MACHINING ALUMINUM ALLOYS by R. L. Templin—Metals Handbook (American Society for Metals), 1948—pp. 786/89.

FABRICATION OF ALUMINUM AND ALUMINUM ALLOY ROD, BAR AND WIRE by W. T. Ennor—Rod and Wire Production Practice (Volume 3; Institute of Metals Division Symposium Series), 1949—pp. 65-77.

CUTTING SHEET ALUMINUM by E. V. Sharpnack, Sr.—Heating, Air Conditioning, Sheet Metal Contractor, Dec. 1954—pp. 34-37.

FINISHES FOR ALUMINUM by Reynolds Metals Company—1951.

FINISHES FOR ALUMINUM by R. V. VandenBerg—Machine Design, Oct. 1953.

FACTORS AFFECTING THE FORMATION OF ANODIC OXIDE COATINGS by M. S. Hunter & P. Fowle—Electrochem. Soc. Jour. 101, Oct. 1954—pp. 514/19.

SURFACE TREATMENTS IMPROVE PROPERTIES, BROADEN USES OF ALUMINUM: PART I by C. C. Cohn—The Iron Age 174: (25), Dec. 16, 1954—pp. 111/14.

NEW ALUMINUM HARD SURFACING PROCESS GIVES HARD, ABRASION-RESISTANT COATING by A. E. Zezula & J. B. Franklin—Western Metals 12, 1954—pp. 53-55.

HARD ANODIZING OF ALUMINUM AND ITS ALLOYS: PART II by A. W. Brace—Electroplating 7, Oct. 1954—pp. 376/79.

PLATING ON ALUMINUM: THE PHOSPHORIC ACID ANODIZING PRETREATMENT by Bernard E. Bunce—Metal Finishing, Jan. 1954—pp. 70-73.

METHOD OF PLATING ALUMINUM DIE CASTINGS by Lynn Sprague—Precision Metal Molding, Dec. 54—pp. 63-64, 66, 70, 91.

NICKEL PLATED ALUMINUM SHEET by J. H. James & Henry Page—Product Engineering, December 1954—pp. 167/70.

PHOSPHORIC ACID ANODIZING OF ALUMINUM AND ITS APPLICATION TO ELECTROPLATING by R. C. Spooner & D. P. Serphim—Metal Ind. 84, May 21, 1951—pp. 449/50.

MECHANICAL PROPERTIES OF ALUMINUM HARD COATINGS by H. A. Johnson—Prod. Eng. 25, Sept. 1954—pp. 136/41.

HOW TOUGH ARE NICKEL AND CHROMIUM ELECTROPLATE FOR ALUMINUM? by Paige, James, and Williams—Product Engineering, Dec. 1953—pp. 162/67.

MECHANICAL PROPERTIES OF ALUMINUM HARD COATINGS by Henry A. Johnson—Product Engineering, Sept. 1954—pp. 136/41.

PREPARING ALUMINUM SURFACES FOR PAINTING by R. I. Wray—Finish 9, No. 4, 1952—p. 4.

NEW USES FOR LACQUER (ON ALUMINUM) by R. I. Wray—American Paint Journal 37, No. 12, 1952—p. 10. Paint, Oil and Chemical Review 115, No. 25, 1952—p. 115.

NEW DEVELOPMENTS IN ARCHITECTURAL PORCELAIN ENAMEL: ALUMINUM by Robert A. Weaver, Jr.—Progressive Architecture, Oct. 1954—p. 111.

PORCELAIN ENAMELED ALUMINUM, A COMPETITIVE PRODUCT by D. R. Goetchins—Ceramic Ind. 62, May 1954—pp. 72-73, 103.

ALUMINIZED COATINGS, A COMPARISON OF HOT-DIP COATING WITH ALUMINUM AND HOT GALVANIZING by A. G. Thompson—Aircraft Engineering 26, Aug. 1954—p. 266.

FINISHING SYSTEMS FOR ALUMINUM DIE CASTINGS by R. V. Vanden Berg—Precision Metal Molding, June 1953—pp. 58-60, 63, 64-65, 69, 88-91.

CHAPTER 4: JOINTS AND CONNECTIONS

Joints and connections of structural members and of other elements of buildings are recognized as the most essential detail problems that the engineer or architect has to face. The clear and simple solution of a joint or connection in any material indicates the hand of the resourceful and imaginative designer because no other detail of the structure presents greater analytical difficulties than the design of the simplest connection.

The engineer is usually aided by semi-empirical formulas and, what is more important, by standardized connection details. The availability of such standard connections has both advantages and disadvantages. While it simplifies and speeds the work of the designer, it may also act as a deterrent to further progress. At the present time there are no generally accepted standardized connections in structural aluminum. Thus the design of such connections is somewhat more time consuming than for conventional materials. As a compensation, however, the greater freedom in developing special details will be appreciated by many engineers.

Aluminum, moreover, when used in the design of joints and connections for structural members and other building elements, has a number of aspects which distinguish it from other materials. These are:

(a) The specific mechanical properties of the material. These properties and their implications are discussed in Chapters 2 and 5.

(b) The special forming and fabricating characteristics of aluminum alloys, which permit many special details not possible in other metals. These aspects are described in Chapter 3.

(c) Finally, the availability of a great number of special joining and connection methods which are particularly suitable for use with aluminum. These are treated here in this chapter.

The various means of joining and fastening fall into two groups: The first, discussed in Sections 4.1 to 4.6, are those which can be considered "traditional" such as riveting, bolting, welding, brazing, soldering, and the use of various standard screw fasteners. These are quite familiar to most engineers and architects. Where the methods of design differ from common practice, details are given here. Welding, also included in this first group, utilizes special methods and equipment that distinguish it from its application in structural steel. Spot and seam welds are of great importance in light-gauge aluminum structures. In many instances, they can result in substantial improvements over riveted connections.

The second group comprises the various unconventional methods of fastening, discussed here in Sections 4.6 to 4.10. These include the use of patented screw fasteners and special rivets, metal stitching, mechanically formed joints and bonding. This second group is of special interest when designing with aluminum, because it permits joints and connections which ordinarily are not possible with other materials. While some of these special fasteners may appear expensive for ordinary applications, they can often be used successfully if the resulting joint effects substantial savings in the weight of the structure. Weight saving, as demonstrated in Chapter 5, is an especially desirable objective in aluminum alloy structures because of the relatively high basic cost of the material.

In addition to this, the advantages of special fasteners can be fully exploited with aluminum because of the possibility of using highly complex extruded shapes at relatively low fabricating costs. Bonding is an unusually interesting example of a non-traditional method of fastening. It

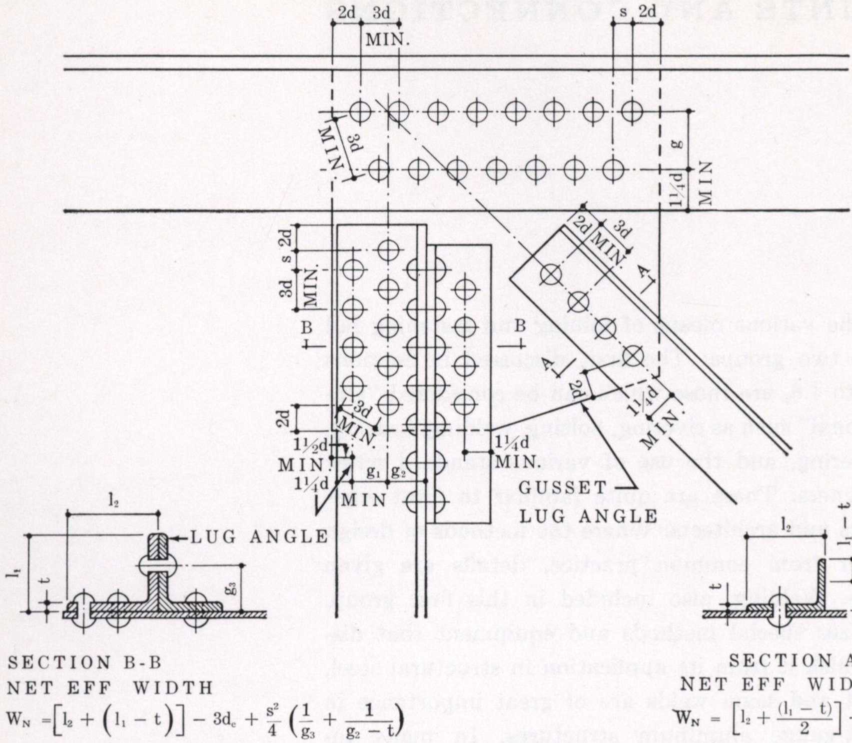


Figure 4-1: *Section B-B*
Net Eff. Width (W_n) = $[l_2 + (l_1 - t)] - 3d + [S^3\!/\!4\,(g_3 + g_2 - t)]$
Section A-A

Net Eff. Width (W_n) $\left[\dfrac{l_2 + (l_1 - t)}{2}\right] d_e$

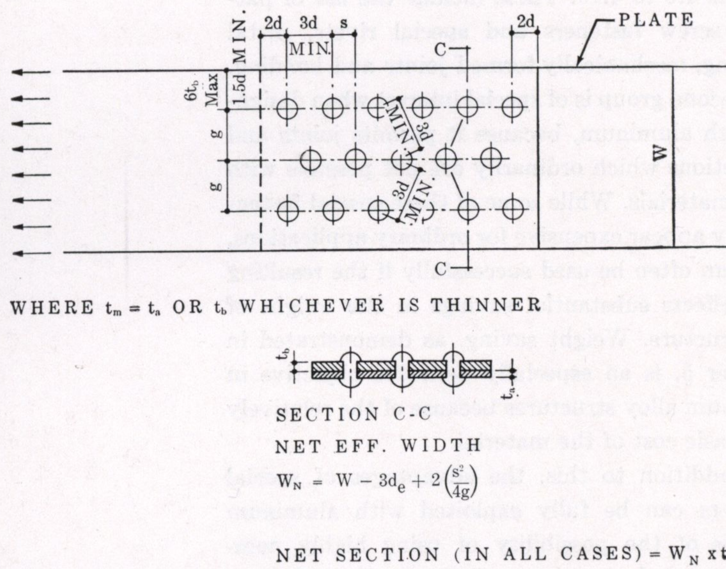


Figure 4-2: *Section A-A* Net Eff. Width (W_n) = $W - 3d_e + 2(S^2/4g)$

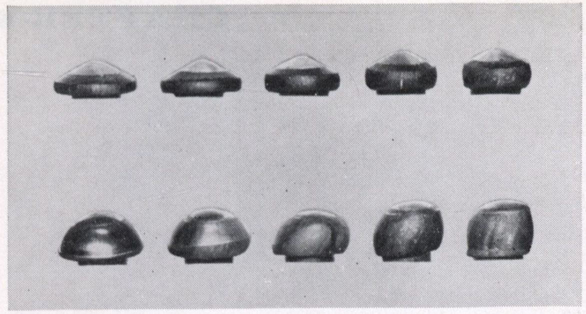


Figure 4-3: Cone-point and button rivet heads resulting from various driving pressures. The tensile strength of each one was within 5 percent of the strongest one.

TABLE 4-1: RIVET ALLOYS FOR SPECIFIC ASSEMBLY ALLOYS

ASSEMBLY ALLOY TEMPER	ASSEMBLY ALLOY	RIVET ALLOY, TEMPER AFTER DRIVING
Any temper	1100	1100-F 3003-F
	2014 2017 2024	2117-T3*
	5052	5056-H321 6053-T6 6053-T61
	6063	6053-T6 6053-T41 6053-T61 6061-T6 6061-T43
Annealed temper	3003-O 3004-O 5052-O	1100-F 3003-F
	3003—all hard tempers 5052—all hard tempers	2117-T3 6053-T41 6053-T61 6061-T31 6061-T43
Hard tempers	2014-T4 2014-T6	2117-T3* 6061-T43* 7277-T41*
	2017-T4	2117-T3*
	2024-T4	2117-T3* 6061-T43*
	6053-T4 6053-T6 6061-T4 6061-T6	6053-T6 6053-T41 6053-T61 6061-T6 6061-T31 6061-T43 7277-T41

* In addition to alloys 2017-T3, 2017-T31, 2017-T41, 2024-T31.

TABLE 4-2: PROPERTIES OF ALUMINUM RIVET ALLOYS

RIVET ALLOY AND TEMPER AFTER DRIVING	RIVET ALLOY AND TEMPER BEFORE DRIVING	DRIVING PROCEDURE	AVERAGE ULTIMATE SHEAR STRENGTH AFTER DRIVING, P.S.I.	REMARKS
1100-F	1100-F	Cold, as rec'd.	11,000	Relatively soft and easy to drive. Properties will not change with prolonged periods of storage.
3003-F	3003-F	Cold, as rec'd.	N.A.	Relatively soft and easy to drive. Properties will not change with prolonged periods of storage.
2117-T3	2117-T4	Cold, as rec'd.	33,000	May be stored indef. with no change in properties.
2017-T3	2017-T4	Cold, as rec'd.	39,000	Limited to small diameter rivets—d = 1/4″
2017-T31	2017-T4	Cold, immediately after reheat & quench	34,000 (after approx. 4 days)	During first 1 or 2 hrs. after quenching, relatively soft and may be driven cold. If allowed to age for more than 2 hrs. after quenching—may be too hard to drive cold and therefore reheat treating is necessary.
2017-T41	2017-T4	Hot, 940°F ± 10°F	33,000	Heated for about 15 min. then driven.
2024-T31	2024-T4	Cold, immediately after quenching	42,000 (after approx. 4 days)	Are very strong, but difficult to drive. Used only in the smaller sizes. d = 1/4″
6053-T41	6053-T4	Hot, 960°F & 1050°F	18,000	Shear value is for rivets driven at temp. 960°F to 980°F; at 1030°F to 1050°F average shear strength = 24,000 psi, normally used in larger diameters.
6053-T6	6053-T6	Cold, as rec'd.	26,000	May be stored indef. with no change in properties.
6053-T61	6053-T61	Cold, as rec'd.	23,000	May be stored indef. with no change in properties. Slightly easier to drive than 6053-T6 rivet.
5056-H321	5056-F	Cold, as rec'd.	29,000	Used primarily for joining magnesium structures. May be stored indef. with no change in properties.
6061-T31	6061-T4	Cold, immediately after quenching	24,000 (after approx. 2 weeks)	26,000 psi approx. 4 months after driving.
6061-T43	6061-T4	Hot, 990°F to 1050°F	24,000 (after approx. 2 weeks)	Heated for about 15 minutes, then driven.
6061-T6	6061-T6	Cold, as rec'd.	26,000	May be stored indef. with no change in properties.
7277-T41	7277-T4	Hot, 850—975°F	38,000	Heated in air about 15 minutes; avoid heating above 975°F as result may be head cracking and impaired resistance to corrosion. Used in larger diameters.

TABLE 4-3: ALLOWABLE DESIGN LOAD, IN KIPS PER RIVET, FOR COLD-DRIVEN 6061-T6 RIVETS SHEAR STRENGTH = 10 KIPS PER SQUARE INCH

DIMENSIONS IN INCHES RIVET DIA.	⅛				5⁄32				3⁄16				¼				5⁄16				⅜			
HOLE DIA.	0.129				0.159				0.191				0.257				0.323				0.386			
AREA OF HOLE	0.0129				0.0199				0.0287				0.0519				0.0819				0.117			
DRILL SIZE	30				21				11				F				P				W			
SINGLE SHEAR	0.13				0.20				0.29				0.52				0.82				1.17			
DOUBLE SHEAR	0.26				0.40				0.57				1.04				1.64				2.34			
BEARING																								
THICKNESS OF PLATE IN INCHES	6061-T6 27 ksi[a]		2117-T3 36 ksi[a]		6061-T6 27 ksi[a]		2117-T3 36 ksi[a]		6061-T6 27 ksi[a]		2117-T3 36 ksi[a]		6061-T6 27 ksi[a]		2117-T3 36 ksi[a]		6061-T6 27 ksi[a]		2117-T3 36 ksi[a]		6061-T6 27 ksi[a]		2117-T3 36 ksi[a]	
	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.
⅛	0.13	0.26	0.13	0.26	0.20	0.40	0.20	0.40	0.29	0.57	0.29	0.57	0.52	0.87[b]	0.52	0.97[c]	0.82	1.09[b]	0.82	1.43[c]	1.17	1.30[b]	1.17	1.74[b]
3⁄16		—		—		—		—	0.29	0.57	0.29	0.57	0.52	1.04	0.52	1.04	0.82	1.62[c]	0.82	1.62[c]	1.17	1.95[b]	1.17	2.19[c]
¼		—		—		—		—		—		—	0.52	1.04	0.52	1.04	0.82	1.64	0.82	1.64	1.17	2.34	1.17	2.34
5⁄16		—		—		—		—		—		—		—		—	0.82	1.64	0.82	1.64	1.17	2.34	1.17	2.34
⅜		—		—		—		—		—		—		—		—		—		—	1.17	2.34	1.17	2.34
7⁄16		—		—		—		—		—		—		—		—		—		—		—		—
½		—		—		—		—		—		—		—		—		—		—		—		—
9⁄16		—		—		—		—		—		—		—		—		—		—		—		—
⅝		—		—		—		—		—		—		—		—		—		—		—		—
¾		—		—		—		—		—		—		—		—		—		—		—		—
⅞		—		—		—		—		—		—		—		—		—		—		—		—
1		—		—		—		—		—		—		—		—		—		—		—		—

[a] Assuming the distance center of rivet to edge of member toward which the pressure of the rivet is directed is not less than twice nominal rivet diameter.
[b] These values are governed by bearing.
[c] These values are governed by reduced shear strengths.
[d] Effective bearing area is the effective diameter times the length in bearing; for countersunk rivets, one half the depth of the countersink shall be deducted from the length.

offers a great many potential advantages, both in structural and in non-load-bearing applications.

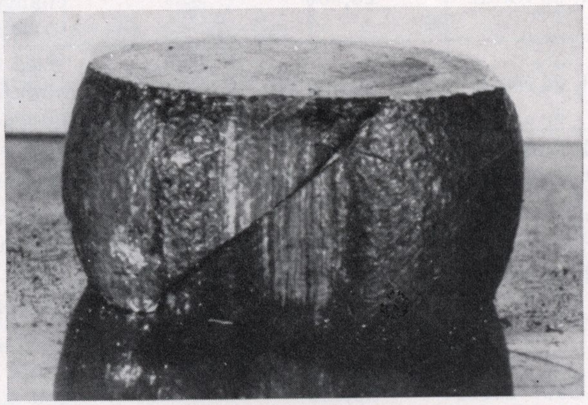


Figure 4-4: Tests on 2024-T31 rivets indicated even this severe cracking had no adverse effect on static strength, fatigue strength or resistance to corrosion. However, defective heads should always be replaced in the interests of good workmanship.

4.1 RIVETING AND BOLTING

LEGEND

- d = Nominal diameter of rivet.
- d_e = Effective diameter (hole diameter).
- D = Weld size in inches.
- g = Gauge.
- G = Grip.
- K = Kips.
- KSI = Kips per square inch.
- l_1, l_2 = Width of angle leg.
- L = Weld length in inches.
- P = Load.
- S = Pitch.
- t_a = Thickest section under rivet head.
- t_b = Thinnest section in single shear joint.
- t_c = Thickness of middle plate in double shear joint.
- t_d = Thinnest section under rivet head.
- W = Width of plate or angle leg through which rivet passes.
- S.S. = Single shear.
- D.S. = Double shear.

IN 6061-T6 STRUCTURES, AND 2117-T3 RIVETS IN 2014-T6 STRUCTURES

7/16				1/2				9/16				5/8				3/4				7/8				1				DIMENSIONS IN INCHES RIVET DIA.
0.453				0.516				0.578				0.641				0.766				0.891				1.016				HOLE DIA.
0.161				0.209				0.262				0.323				0.461				0.624				0.811				AREA OF HOLE
29/64				33/64				37/64				41/64				49/64				57/64				1 1/64				DRILL SIZE
1.61				2.09				2.62				3.23				4.61				6.24				8.11				SINGLE SHEAR
3.22				4.18				5.25				6.45				9.22				12.47				16.22				DOUBLE SHEAR
																												BEARING
6061-T6 27 ksi[a]		2117-T3 36 ksi[a]		6061-T6 27 ksi[a]		2117-T3 36 ksi[a]		6061-T6 27 ksi[a]		2117-T3 36 ksi[a]		6061-T6 27 ksi[a]		2117-T3 36 ksi[a]		6061-T6 27 ksi[a]		2117-T3 36 ksi[a]		6061-T6 27 ksi[a]		2117-T3 36 ksi[a]		6061-T6 27 ksi[a]		2117-T3 36 ksi[a]		THICKNESS OF PLATE IN INCHES
S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	
1.53[b]	1.53[b]	1.58[c]	2.04[b]	1.74[b]	1.74[b]	2.01[c]	2.32[b]	1.95[b]	1.95[b]	2.52[c]	2.60[b]	2.16[b]	2.16[b]	2.88[b]	2.88[b]	—		—		—		—		—		—		1/8
1.61	2.29[b]	1.61	2.88[c]	2.09	2.61[b]	2.09	3.48[b]	2.62	2.93[b]	2.62	3.90[b]	3.18[c]	3.25[b]	3.18[c]	4.33[b]	3.88[b]	3.88[b]	4.42[c]	5.17[b]	4.51[b]	4.51[b]	5.82[c]	6.02[b]	—		—		3/16
1.61	3.06[b]	1.61	3.12[c]	2.09	3.48[b]	2.09	3.91[c]	2.62	3.90[b]	2.62	4.74[c]	3.23	4.33[b]	3.23	5.62[c]	4.61	5.17[b]	4.61	6.89[b]	6.02[b]	6.02[b]	6.11[c]	8.02[b]	6.86[b]	6.86[b]	7.78[c]	9.14[b]	1/4
1.61	3.22	1.61	3.22	2.09	4.13[c]	2.09	4.13[c]	2.62	4.88[b]	2.62	5.04[c]	3.23	5.41[b]	3.23	6.03[c]	4.61	6.46[b]	4.61	8.14[c]	6.24	7.52[b]	6.24	10.02[b]	8.04[c]	8.57[b]	8.04[c]	11.43[b]	5/16
1.61	3.22	1.61	3.22	2.09	4.18	2.09	4.18	2.62	5.25	2.62	5.25	3.23	6.31[c]	3.23	6.31[c]	4.61	7.76[b]	4.61	8.62[c]	6.24	9.02[b]	6.24	11.12[c]	8.11	10.29[b]	8.11	13.72[b]	3/8
1.61	3.22	1.61	3.22	2.09	4.18	2.09	4.18	2.62	5.25	2.62	5.25	3.23	6.45	3.23	6.45	4.61	8.97[c]	4.61	8.97[c]	6.24	10.52[b]	6.24	11.66[c]	8.11	12.00[b]	8.11	14.58[c]	7/16
—		—		2.09	4.18	2.09	4.18	2.62	5.25	2.62	5.25	3.23	6.45	3.23	6.45	4.61	9.22	4.61	9.22	6.24	12.03[b]	6.24	12.07[c]	8.11	13.72[b]	8.11	15.16[c]	1/2
—		—		—		—		2.62	5.25	2.62	5.25	3.23	6.45	3.23	6.45	4.61	9.22	4.61	9.22	6.24	12.39[c]	6.24	12.39[c]	8.11	15.43[b]	8.11	15.64[c]	9/16
—		—		—		—		—		—		3.23	6.45	3.23	6.45	4.61	9.22	4.61	9.22	6.24	12.47	6.24	12.47	8.11	16.00[c]	8.11	16.00[c]	5/8
—		—		—		—		—		—		—		—		4.61	9.22	4.61	9.22	6.24	12.47	6.24	12.47	8.11	16.22	8.11	16.22	3/4
—		—		—		—		—		—		—		—		—		—		6.24	12.47	6.24	12.47	8.11	16.22	8.11	16.22	7/8
—		—		—		—		—		—		—		—		—		—		—		—		8.11	16.22	8.11	16.22	1

Design of riveted connections in aluminum parallels, in general, that of steel; but since the margin between yield strength and ultimate strength in aluminum is less than that in structural steel, it is advisable to be somewhat more conservative when designing in aluminum than is customary in structural steel practice. This consideration is of importance because in a riveted joint the end rivets take a larger than average share of the load, even under axial load application; the rivet loads will be equalized only after plastic deformation has occurred within the joint.

The initial consideration for designing the joint is to select a rivet alloy that will allow the use of the highest shear stress compatible with the limitations of the alloy being joined, and the driving and predriving procedures available. The rivet alloys to be used with the various sheet, plate and structural

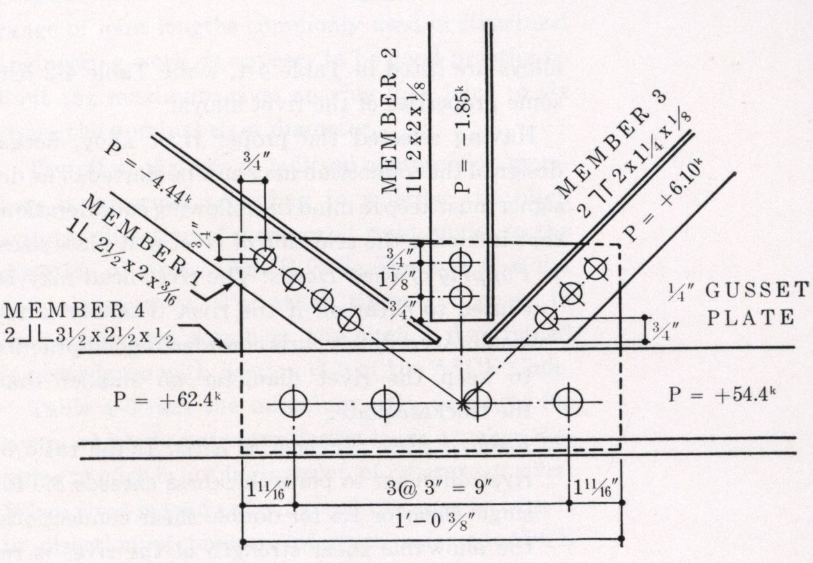


Figure 4-5: Typical riveted joint in aluminum. See Example 4-1 on Page 87.

TABLE 4-4: ALLOWABLE DESIGN LOAD, IN KIPS PER RIVET, FOR HOT-DRIVEN 6061-T6 RIVETS IN 6061-T6 STRUCTURES, OR 6061-T6 RIVETS IN 2014-T6 STRUCTURES
SHEAR STRENGTH = 8 KIPS PER SQUARE INCH

DIMENSIONS IN INCHES RIVET DIA.	3/8	7/16	1/2	9/16	5/8	3/4	7/8	1
HOLE DIA.	0.397	0.469	0.531	0.594	0.656	0.781	0.922	1.063
AREA OF HOLE	0.124	0.173	0.221	0.278	0.338	0.479	0.667	0.887
DRILL SIZE	X	15/32	17/32	19/32	21/32	25/32	59/64	1 1/16
SINGLE SHEAR	0.99	1.38	1.77	2.22	2.70	3.83	5.34	7.10
DOUBLE SHEAR	1.98	2.76	3.54	4.44	5.41	7.67	10.68	14.20

BEARING[d]																																
THICKNESS OF PLATE INCH	6061-T6 27 ksi[a]		2014-T6 36 ksi[a]		6061-T6 27 ksi[a]		2014-T6 36 ksi[a]		6061-T6 27 ksi[a]		2014-T6 36 ksi[a]		6061-T6 27 ksi[a]		2014-T6 36 ksi[a]		6061-T6 27 ksi[a]		2014-T6 36 ksi[a]		6061-T6 27 ksi[a]		2014-T6 36 ksi[a]		6061-T6 27 ksi[a]		2014-T6 36 ksi[a]		6061-T6 27 ksi[a]		2014-T6 36 ksi[a]	
	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.
1/8	0.99	1.34[b]	0.99	1.60[c]	1.38[c]	1.58[b]	1.35[c]	2.05[c]	1.70[c]	1.79[b]	1.70[c]	2.39[b]	2.00[c]	2.00[b]	2.08[c]	2.67[b]	2.21[b]	2.21[b]	2.49[c]	2.95[b]	—		—		—		—		—		—	
3/16	0.99	1.85[c]	0.99	1.85[c]	1.38	2.37[b]	1.38	2.47[c]	1.77	2.69[b]	1.77	3.01[c]	2.22	3.01[b]	2.22	3.57[c]	2.66[c]	3.32[b]	2.66[c]	4.12[c]	3.68[c]	3.95[b]	3.68[c]	5.17[c]	4.67[b]	4.67[b]	4.98[c]	6.22[b]	—		—	
1/4	0.99	1.98	0.99	1.98	1.38	2.68[c]	1.38	2.68[c]	1.77	3.31[c]	1.77	3.31[c]	2.22	4.00[c]	2.22	4.00[c]	2.70	4.43[b]	2.70	4.71[c]	3.83	5.27[b]	3.83	6.17[c]	5.23[c]	6.22[b]	5.23[c]	7.91[c]	6.82[c]	7.18[b]	6.82[c]	9.59[c]
5/16	0.99	1.98	0.99	1.98	1.38	2.76	1.38	2.76	1.77	3.50[c]	1.77	3.50[c]	2.22	4.26[c]	2.22	4.26[c]	2.70	5.06[c]	2.70	5.06[c]	3.83	6.59[b]	3.83	6.77[c]	5.34	7.78[b]	5.34	8.88[c]	7.04[c]	8.97[b]	7.04[c]	10.88[c]
3/8	0.99	1.98	0.99	1.98	1.38	2.76	1.38	2.76	1.77	3.54	1.77	3.54	2.22	4.44	2.22	4.44	2.70	5.29[c]	2.70	5.29[c]	3.83	7.17[c]	3.83	7.17[c]	5.34	9.34[b]	5.34	9.53[c]	7.10	10.76[b]	7.10	12.04[c]
7/16	—		—		1.38	2.76	1.38	2.76	1.77	3.54	1.77	3.54	2.22	4.44	2.22	4.44	2 70	5.41	2.70	5.41	3.83	7.46[c]	3.83	7.46[c]	5.34	9.99[c]	5.34	9.99[c]	7.10	12.56[b]	7.10	12.77[c]
1/2	—		—		—		—		1.77	3.54	1.77	3.54	2.22	4.44	2.22	4.44	2.70	5.41	2.70	5.41	3.83	7.67	3.83	7.67	5.34	10.34[c]	5.34	10.34[c]	7.10	13.28[c]	7.10	13.28[c]
9/16	—		—		—		—		—		—		2.22	4.44	2.22	4.44	2.70	5.41	2.70	5.41	3.83	7.67	3.83	7.67	5.34	10.61[c]	5.34	10.61[c]	7.10	13.69[c]	7.10	13.69[c]
5/8	—		—		—		—		—		—		—		—		2.70	5.41	2.70	5.41	3.83	7.67	3.83	7.67	5.34	10.68	5.34	10.68	7.10	14.02[c]	7.10	14.02[c]
3/4	—		—		—		—		—		—		—		—		—		—		3.83	7.67	3.83	7.67	5.34	10.68	5.34	10.68	7.10	14.20	7.10	14.20
7/8	—		—		—		—		—		—		—		—		—		—		—		—		5.34	10.68	5.34	10.68	7.10	14.20	7.10	14.20
1	—		—		—		—		—		—		—		—		—		—		—		—		—		—		—		—	

[a] Assuming the distance from center of rivet to edge of member toward which the pressure of the rivet is not less than twice the nominal diameter.
[b] These values are governed by bearing.
[c] These values are governed by reduced shear strengths.
[d] Effective bearing area is the effective diameter times the length in bearing; for countersunk rivets, one half the depth of countersink shall be deducted from the length.

alloys are listed in Table 4-1, while Table 4-2 lists some properties of the rivet alloys.

Having selected the proper rivet alloy, actual design of the connection may now be started. The designer must keep in mind the following considerations that influence the selection of rivet and plate sizes:

1. *Popping of Rivet Heads:* The rivet head may be caused to shear off if the rivet diameter is too small. Accordingly, it is considered good practice to keep the rivet diameter no smaller than the thickest plate.
2. *Reduced Shear Strength of Rivet:* If the ratio of rivet diameter to plate thickness exceeds 3.0 for single shear or 1.5 for double shear connections, the allowable shear strength of the rivet is reduced.

Allowable shear and bearing values for cold-driven and hot-driven rivets are indicated in Tables 4-3 and 4-4, respectively. These two tables cover the range of the most commonly used combinations of rivet alloys and structural alloys. Reduction of rivet value is based on the following formulas:*

Single shear working strength =

$$\textit{Basic allowable single shear strength} \times [1 - 0.04\ (d/t_c - 3)]$$

Double shear working strength =

$$\textit{Basic allowable double shear strength} \times [1 - 0.13\ (d/t_c - 1.5)]$$

It should be specially noted that here the area in shear of a rivet is taken as the area of the hole, whereas in steel the area of the rivet only is used.

* N.A.C.A. Tech. Note #942, July 1944: "The Shear Strength of Aluminum Alloy Driven Rivets as Affected by Increasing d/t Ratios."

TABLE 4-5: MAXIMUM DIAMETER OF RIVET OR BOLT IN ANGLE WHEN ANGLE IS NOT DETERMINED BY CALCULATED STRESS

ANGLE LEG INCH	MAX. RIVET OR BOLT DIAMETER INCH
3½	1
3	⅞
2½	¾
2	⅝
1½	½

TABLE 4-6 MINIMUM EDGE DISTANCE

a) FOR NON-LOAD BEARING RIVETS OR BOLTS.
b) FOR LOAD BEARING RIVETS OR BOLTS NOT IN THE DIRECTION OF THE LOAD.

RIVET OR BOLT DIAMETER (INCH)	IN ROLLED EDGE OF* PLATE; IN SAWED OR PLANED EDGE OF ANY SECTION (INCH)	IN ROLLED EDGE OF STRUCTURAL SHAPES (INCH)
⅛	3/16	3/16
3/16	5/16	¼
¼	⅜	5/16
5/16	½	7/16
⅜	9/16	½
7/16	11/16	9/16
½	¾	⅝
9/16	⅞	¾
⅝	1 5/16	1 3/16
¾	1⅛	1 5/16
⅞	1 5/16	1⅛
1	1½	1¼

* NOTE: The distance from the edge of a plate to the nearest rivet line shall not exceed six times the thickness of the plate. ASCE Code, Sect. G-11.

3. *Reduction of Load Due to Excessive Grip:* The full allowable strength of the rivet may be used if the grip of the rivets is equal to or less than 4.5 times the diameter of the rivet. If the grip of the rivet should be greater than the aforementioned value, then the allowable load on the rivet must be reduced. (ASCE Code, Section G-7).

4. *Damage to Plate or Sheet:* Maintain a ratio of rivet diameter to plate thickness of less than 3. If this ratio should exceed 3, then special care must be taken in driving the rivet head so as not to damage the material under the rivet head. There is no reduction in allowable shear strength of the rivet, except as covered in item (2) above.

5. *When Connecting Angles:* If the angle has been determined by a calculated stress, then maintain diameter of rivets in angle less than one-quarter the width of the leg of the angle. If the angle has not been determined by a calculated stress, then the diameter of the rivets may be determined as shown in Table 4-5.

Tension connections for single angles must provide for stresses in the outstanding leg (ASCE Code, Section G-6.) See Figure 4-1 for determining net effective sections for single angles.

In accordance with ASCE Code requirements, the minimum spacing of rivets in a joint shall be not less than three times the nominal diameter of the rivet. The maximum spacing of rivets in a joint, however, is not specifically limited.

In tests* conducted by S. C. Redshaw it was shown that rivet efficiency decreases with increasing rivet pitch and increasing number of rows of rivets within a joint. Although this decrease in rivet efficiency can be considered negligible within the range of joint lengths commonly used in structural engineering work, it appears to be good practice to limit the maximum rivet spacing in a joint to six times the nominal rivet diameter.

The pitch of rivets in built-up compression members is governed according to whether the pitch is in the direction of stress or at right angles to the direction of stress. (ASCE Code, Sections G-8 and G-9, respectively.) For stitch rivets and rivets in built-up tension members, the pitch is determined in accordance with Section G-9 of the ASCE Code.

Table 4-6 lists the minimum edge distances for rivets which do not carry design loads or when distance to edge is not in direction of pressure of rivet. When rivet is load carrying and distance to edge is in direction of pressure of rivet, refer to ASCE

* Reported at the Symposium on "Welding & Riveting Larger Aluminum Structures," London, November 1951.

TABLE 4-7: ALLOWABLE DESIGN LOAD, IN KIPS PER BOLT, FOR TURNED BOLTS IN REAMED HOLES; 2024-T4 BOLTS IN 2014-T6 STRUCTURES, OR 2024-T4 BOLTS IN 6061-T6 STRUCTURES SHEAR STRENGTH = 12 KIPS PER SQUARE INCH

Holes for turned bolts to be reamed to give a driving fit.

DIMENSIONS IN INCHES BOLT DIA.	3/8				7/16				1/2				9/16				5/8				3/4				7/8				1			
AREA OF BOLT	0.110				0.151				0.197				0.249				0.307				0.442				0.601				0.785			
SINGLE SHEAR	1.32				1.81				2.36				2.99				3.68				5.30				7.21				7.21			
DOUBLE SHEAR	2.64				3.62				4.72				5.97				7.36				10.60				14.42				18.84			
BEARING																																
THICKNESS OF PLATE IN INCHES	6061-T6 27 ksi[a]		2014-T6 36 ksi[a]		6061-T6 27 ksi[a]		2014-T6 36 ksi[a]		6061-T6 27 ksi[a]		2914-T6 36 ksi[a]		6061-T6 27 ksi[a]		2014-T6 36 ksi[a]		6061-T6 27 ksi[a]		2014-T6 36 ksi[a]		6061-T6 27 ksi[a]		2041-T6 36 ksi[a]		6061-T6 27 ksi[a]		2014-T6 36 ksi[a]		6061-T6 27 ksi[a]		2014-T6 36 ksi[a]	
	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.	S.S.	D.S.
1/8	1.32	1.27[b]	1.32	1.69[b]	1.48[b]	1.48[b]	1.78[c]	1.96[b]	1.69[b]	1.69[b]	2.25[b]	2.25[b]	1.90[b]	1.90[b]	2.53[b]	2.53[b]	2.11[b]	2.11[b]	2.81[b]	2.81[b]	—		—		—		—		—		—	
3/16	1.32	1.90[b]	1.32	2.46[c]	1.81	2.21[b]	1.81	2.95[b]	2.36	2.53[b]	2.36	3.38[b]	2.85[b]	2.85[b]	2.99	3.80[b]	3.16[b]	3.16[b]	3.63[c]	4.22[b]	3.80[b]	3.80[b]	5.06[b]	5.06[c]	4.43[b]	4.43[b]	5.91[b]	5.91[b]	—		—	
1/4	1.32	2.64	1.32	2.64	1.81	2.93[b]	1.81	3.54[c]	2.36	3.38[b]	2.36	4.42[c]	2.99	3.80[b]	2.99	5.06[b]	3.68	4.22[b]	3.68	5.62[b]	5.06[b]	5.06[b]	5.30	6.75[b]	5.91[b]	5.91[b]	6.92[c]	7.88[b]	6.75[b]	6.75[b]	9.00[b]	9.00.
5/16	1.32	2.64	1.32	2.64	1.81	3.62	1.81	3.62	2.36	4.22[b]	2.36	4.66[c]	2.99	4.75[b]	2.99	5.74[c]	3.68	5.27[b]	3.68	6.88[c]	5.30	6.33[b]	5.30	8.44[b]	7.21	7.30[b]	7.21	9.84[b]	8.44[b]	8.44[b]	9.34[c]	11.25[b]
3/8	1.32	2.64	1.32	2.64	1.81	3.62	1.81	3.62	2.36	4.72	2.36	4.72	2.99	5.97	2.99	5.97	3.68	6.33[b]	3.68	7.22[c]	5.30	7.59[b]	5.30	9 92[c]	7.21	8.86[b]	7.21	11.81[b]	9.42	10.13[b]	9.42	13.50[b]
7/16	—		—		1.81	3.62	1.81	3.62	2.36	4.72	2.36	4.72	2.99	5.97	2.99	5.97	3.68	7.36	3.68	7.36	5.30	8.86[b]	5.30	10.33[c]	7.21	10.34[b]	7.21	13.48[c]	9.42	11.81[b]	9.42	15.75[b]
1/2	—		—		—		—		2.36	4.72	2.36	4.72	2.99	5.97	2.99	5.97	3.68	7.36	3.68	7.36	5.30	10.60	5.30	10.60	7.21	11.81[b]	7.21	13.96[c]	9.42	13.50[b]	9.42	17.61[c]
9/16	—		—		—		—		—		—		2.99	5.97	2.99	5.97	3.68	7.36	3.68	7.36	5.30	10.60	5.30	10.60	7.21	13.28[b]	7.21	14.24[c]	9.42	15.19[b]	9.42	18.10[c]
5/8	—		—		—		—		—		—		—		—		3.68	7.36	3.68	7.36	5.30	10.60	5.30	10.60	7.21	14.42	7 21	14.42	9.42	16.88[b]	9.42	18.58[c]
3/4	—		—		—		—		—		—		—		—		—		—		5.30	10.60	5.30	10.60	7.21	14.42	7.21	14.42	9.42	18.84	9.42	18.84
7/8	—		—		—		—		—		—		—		—		—		—		—		—		7.21	14.42	7.21	14.42	9.42	18.84	9.42	18.84
1	—		—		—		—		—		—		—		—		—		—		—		—		—		—		9.42	18.84	9.42	18.84

[a] Assuming the distance from center of bolt to edge of member toward which the pressure of the bolt is directed is not less than twice the nominal diameter.
[b] These values are governed by bearing.
[c] These values are governed by reduced shear strength.
[d] Effective bearing area is the effective diameter times the length in bearing.

Code, Section G-1, Exception (b). Figures 4-1 and 4-2 show net width of sections and recommended edge distances and unit pitches.

In general, tests of various riveted joints have shown with respect to fatigue strength that:

—Riveted joints in double shear have better fatigue strength than in single shear.

—Fatigue strength tends to increase with increased number of rows of rivets.

—The variation in fatigue between hot and cold-driven aluminum rivets is negligible.

—Fatigue strength increases with size of rivet.

—Fatigue strength of joints is related to the fatigue strength of the basic alloy.

—Butt-riveted joints have greater fatigue strength than lap joints. Similarly, a butt joint having a double splice plate will have greater fatigue strength than one having a single splice plate.

Tests show that the driven heads of rivets, even if badly cracked, are satisfactory from the standpoint of static strength, fatigue strength and resistance to corrosion. Rivets heads in Figures 4-3 and 4-4 were tested in tension to determine how well formed a head had to be in order to develop full strength. The tensile strengths of all of the rivets in Figure 4-3 were within 5 percent of the strongest one. This indicates that minor deviations from the theoretically desired shape of head are not cause for concern or replacement. While cracks in rivet heads (Figure 4-4) have no adverse effect on the strength of a rivet, good workmanship requires their replacement.

Bolted Connections: The use of bolts in a joint entails no more problems than the use of rivets. The same design considerations may be used except that item (4) (page 85), pertaining to Damage to Plate or Sheet, need not be considered. Table

TABLE 4-8: LIMITATIONS OF RIVET DIAMETER
(ITEMS 1 TO 5 INCLUSIVE OF TEXT)

LIMITATION		Diameter of rivet for member 1	2	3	4
(1) Popping of rivet head	$[d \geqq t_a]$	$\geqq 1/4''$	$\geqq 1/4''$	$\geqq 1/8''$	$\geqq 1/2''$
(2) Reduced shear strength of rivet	D.S. $[d/t_b \leqq 1.5]$	—	—	$\leqq 3/8''$	$\leqq 3/8''$
	S.S. $[d/t_c \leqq 3.0]$	$\leqq 9/16''$	$\leqq 3/8''$	—	—
(3) Reduction of load due to excessive grip	$\left[d \geqq \frac{G}{4.5}\right]$	$\geqq 0.097''$	$\geqq 0.083''$	$\geqq 0.111''$	$\geqq 0.278''$
(4) Damage to plate	$[d/t_b \leqq 3.0]$	$\leqq 9/16''$	$\leqq 3/8''$	$\leqq 3/8''$	$\leqq 1\frac{1}{2}''$
(5) Connecting angles	$[d \leqq 1/4\ w]$	$\leqq 5/8''$	$\leqq 1/2''$	$\leqq 1/2''$	$\leqq 7/8''$

For Members 1, 2 and 3: use 3/8″ diameter rivet

Table 4-3 $\begin{cases}\text{drill size} = \text{W} \\ \text{hole diameter} = 0.386''\end{cases}$

For Member 4: use 1/2″ diameter rivet

Table 4-3 $\begin{cases}\text{drill size} = 33/64 \\ \text{hole diameter} = 0.516''\end{cases}$

NOTE: The use of a 1/2″ diameter rivet in Member 4 will necessitate a reduction of the allowable shear strength of the rivet.

TABLE 4-9: EDGE DISTANCE AND RIVET PITCH DETERMINATION

ITEM CONSIDERED	RIVET DIAMETER 3/8″	1/2″
Minimum edge distance in direction of pressure of rivet = 2d	3/4″	1″
Minimum edge distance not in direction of pressure of rivet (Table 4-6)	1/2″	5/8″
Minimum rivet pitch = 3d	1 1/8″	1 1/2″
Maximum rivet pitch = 6d	2 1/4″	3″

4-7 lists the allowable shear and bearing values for turned bolts of aluminum alloy 2024-T4 (in reamed holes) in 2014-T6 and 6061-T6 structures.

Design of a typical riveted joint is illustrated in the following example:

EXAMPLE 4-1:

Problem: To determine the number and size of rivets for the riveted joint shown in Figure 4-5.

Assumed assembly alloy is 6061-T6. Rivet alloy after cold driving is 6061-T6 (Tables 4-1 and 4-2).

The proper rivet diameters to use for this are calculated and shown in Table 4-8.

Edge distances and rivet pitch for selected rivet diameters are shown in Table 4-9.

Rivets required to join Member 1 (one angle 2 1/2 x 2 x 3/16) to 1/4″ gusset plate:

$P = -4.44^K$

3/8″ diameter rivet in single shear

Thinnest member joined = 3/16 inch

From Table 4-3, rivet value = 1.17^K

Number of rivets required =

$$\frac{4.44}{1.17} = 3.79 \text{ (use four rivets)}$$

Rivets required to join Member 2 (one angle 2 x 2 x 1/8) to 1/4″ gusset plate:

$P = -1.85^K$

3/8″ diameter rivet in single shear

Thinnest member joined = 1/8 inch

From Table 4-3, rivet value = 1.17^K

Number of rivets required =

$$\frac{1.85}{1.17} = 1.98 \text{ (use two rivets)}$$

Rivets required to join Member 3 (two angles 2 x 1 1/4 x 1/8) to 1/4″ gusset plate:

$P = 6.10^K$

3/8″ diameter rivet in double shear

Middle plate of connection = ¼ inch
From Table 4-3, rivet value = 2.34^K
Number of rivets required =
$\frac{6.10}{2.34} = 2.61$ (use three rivets)

Tension member, check for net area:
Gross area (one angle) = 0.390 inch²
Area removed by rivet =
0.386″ (⅛″) = 0.048 inch²
(Refer to Figure 4-7)
Net effective area (one angle) =
0.390 − 0.048 = 0.342 inch²
Net effective area (both angles) = 0.684 inch²
$P_{allowable}$ = 0.684 inch² (15.0 ksi) = 10.26^K where 15.0 ksi is allowable unit stress in tension.
Member satisfactory since $10.26^K > 6.10^K$

Rivets required to join ¼″ gusset plate to Member 4 (two angles 3½ x 2½ x ½):
$P = 62.4^K - 54.4^K = 8.0^K$
½″ diameter rivet in double shear
Middle plate of connection = ¼″
From Table 4-3, rivet value = 3.48^K

Figure 4-6: After tack welding, complicated shaped units such as this are easily finish welded with little distortion by skillful use of the torch.

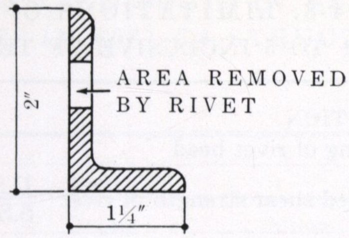


Figure 4-7: Area removed by rivet. = 0.386″ (⅛″) = 0.048 inch.²

$$\text{Number of Rivets Required} = \frac{8.0}{3.48} = 2.3$$

It is necessary, because of the length of the gusset plate, to add one extra rivet so that pitch does not exceed 3 inches (Refer to Table 4-9). Therefore use four rivets.

4.2 WELDING

Welding is a method of forming a metallurgical bond between two or more members of an assembly. The selection of a welding process for a particular job depends upon conditions to be encountered in service and the aluminum alloys employed. In general, the heat-treatable alloys are not as suitable for welding as the non-heat-treatable group. (See Section 2.2.) Heat-treatable alloys should be heat treated after welding to develop maximum strength. Much strength will be lost by partial annealing if welded after heat treatment.

When cold-work tempers of non-heat-treatable alloys are fusion welded, partial annealing effects are again encountered at the weld area. Resistance welding has practically no effect on the temper since the weld is made so quickly that the adjoining area does not heat appreciably. Cold-work tempers of non-heat-treatable alloys can be spot welded with little or no reduction in strength. Annealed material (O temper) has essentially the same strength when welded as before welding. In Table 2-4, Columns 44–48 show weldability ratings for the various aluminum alloys.

Preheating of the pieces to be welded is often recommended. When working with thick plate on structural members, heat is conducted from the weld zone rapidly, and a high rate of heat input is necessary. Otherwise weld metal is deposited upon

a relatively cool plate, thereby making for incomplete and unsatisfactory penetration. Preheating the plate reduces the heat loss; but the preheating (except when welding annealed material) may spread the thermal disturbances over a much greater area around the weld zone than when the welds can be completed without preheating. It would appear, then, that a process giving a heat input sufficiently high to preclude the use of preheating is preferable.

Except when melting down sheet edges on certain types of sheet joints, filler metal is required in all fusion welding. It is important that the filler metal should resolidify at a temperature lower than does the base metal. Aluminum alloys solidify over a temperature range. Throughout this range there exists in the weld zone a mixture of solid and liquid particles constituting the weld pool. The contraction stresses imposed by the thermal and solidification contraction of this pool, if transmitted to the base metal, may cause cracking to occur at the edge of the weld. But if the filler metal solidifies after the base metal, it will absorb these stresses.

Therefore the filler metal must not only have a low melting point, but also a high degree of fluidity, along with sufficient strength and ductility to absorb the contraction stresses. Commercially pure aluminum (1100) has a high ductility and provides maximum resistance to corrosion when used as filler metal. Where greater strength is required and where the cracking tendency must be minimized, alloy 4043 is recommended and widely used. Certain other alloys may also be employed.

Welding fluxes are required with some of the welding processes. The flux combines chemically with the aluminum oxide and floats to the top of the weld pool as a slag. This slag must not be trapped in the weld or corrosion will result. This factor is particularly important in fillet welds.

Table 4-10 lists the various welding processes suitable for use with aluminum alloys. Some of the more important processes are discussed here.

GAS WELDING is the earliest welding process successfully employed on aluminum. The oxyacetylene flame is used most widely because of its availability.

Figure 4-8: Welding ¼-inch thick aluminum wheel sections to hub with inert-gas-shielded metallic arc (Aircomatic) at 70 inches per minute weld speed, using 43S $\frac{3}{16}$-inch diameter wire for filler metal, 230 amperes direct current, reverse polarity, and 30 cubic feet per hour of argon. Motor-driven fixture.

Figure 4-9: This 8-inch aluminum pipe line of 6063-T6 alloy carries fuel gas at 200 pounds per square inch pressure. All joints were made by inert-gas-shielded tungsten-arc (Heliarc) process. The ¼-inch thick walls were welded in one pass using $\frac{3}{16}$-inch diameter 5% silicon rod at 300 amperes. Most welding was downhand as helper turned pipe (roll welding) in field, making up 200-foot lengths. Subsequently these 200-foot sections were connected into the line by bell-hole welding.

TABLE 4-10: STANDARD WELDING PROCESSES FOR ALUMINUM

TYPES OF WELDS	DESCRIPTION OF PROCESS	TYPE OF GAS USED	ALLOYS	FLUX	ELEC-TRODES	RANGE OF METAL THICKNESS MIN. (ORDINARY PRACTICE) INCH	RANGE OF METAL THICKNESS MAX. INCH
GAS WELDING	Employs an oxyacetylene, oxyhydrogen or other fuel gas flame to melt parent metal & usually filler material to make a weld.	Oxyhydrogen Oxyacetylene Oxybutane Oxypropane	SEE TABLE 2-4 CHAPTER II	Flux coated filler rod.	Not used	.031	1
ARC WELDING (a) to (f)							
(a) metal-arc welding	Is the process wherein the arc between a flux-coated electrode & the work heats both the electrode & the work & deposits electrode metal to form weld bead.	—		Heavily flux coated electrodes. Electrodes of Al 25, & Al 435.		.125	No limit. Experience thus far up to 3″ thickness.
(b) carbon-arc welding	Utilizes an arc between a carbon electrode & the work for heat. Added filler metal is usually provided.	Oxyhydrogen or Oxyacetylene		Lightly flux coating on filler rod.	Carbon electrode	.125	No limit. Up to 3″ thus far.
(c) Atomic-hydrogen arc welding	Is done with a special torch that maintains an arc free of the work. Heat is conveyed to the work by molecular breakdown & recombination of hydrogen that flows through the arc.	Hydrogen		Fluxed rod = to that used for gas-welding	Two tungsten electrodes	.031	1
(d) Inert-gas-shielded tungsten-arc welding	Uses heat from an arc between the work & a non-consumable tungsten electrode. The arc is enveloped by a stream of inert gas. No flux is needed.	Argon or Helium		Not required	One tungsten electrode (non-consumable)	.031	1
(e) Inert-gas-shielded metal-arc welding	Employs an automatically-fed, bare electrode. The arc is enveloped by a stream of inert gas. No flux is needed.	Argon or Helium		Not required	Consumable metal electrode instead of filler rod.	.093	No limit. Experience thus far up to 3″ thickness.
(f) Multi-arc welding	Employs two arcs. One arc is struck between a coated filler rod & the work to deposit weld beads, the other arc flattens & fuses the beads into the work.			Heavily fluxed rod	—	—	—
STUD WELDING	Is a process which welds studs directly to work surface, with either a gas-shielded or unshielded process.	For gas-shielded process Argon or Helium		Not required in either process	Not used	—	—
RESISTANCE WELDING (a) to (e)							
(a) Spot welding	Is a method that forms localized areas of cast metal between work pieces by combining the heat of resistance to electric current with the application of mechanical pressure.	—		Not used	"Elkaloya metal" & "Mallory 3 metal" electrodes	Foil	3/16; experimental procedures developed for metal up to 1/2″
(b) Projection welding	Similar to spot welding. Part to be joined has raised points or lines to concentrate welding current to these areas.	—		Not used	Not used	Experimental work need be done before sat. application to flat sheet work can be accomplished.	
(c) Seam welding	Is a form of spot welding in which a row of spots is made with precise control so that the welds can, if required, overlap to form pressure-tight seams.	—		Not used	Roller electrode	.010	3/16
(d) Flash welding	Applies heat by establishing an arc between the pieces to be joined. Then they are pressed together to squeeze out excess molten metal & to consolidate the joint.	—		Not used	Not used	—	—
(e) Percussion welding	Employs high intensity heat to rapidly heat the surfaces to be joined followed by a pressure applied as a hammer blow.	—		Not used	Not used	—	—
PRESSURE WELDING	Is done by applying pressure to suitably prepared surfaces below the melting point of the parts, or by pressure on cold surfaces.	—		Not used	Not used	—	—

LIMITATIONS, PRECAUTIONS & DISADVANTAGES
1. Parts & filler rods must be fluxed. 2. All flux must be cleaned after welding. 3. Parts must be preheated at points of welds to ensure proper penetration. 4. Welding speeds are dependent on the angle of the torch, i.e., the flatter the flame, the faster the weld. 5. Not recommended for heat-treatable alloys. 6. For flush welds, the weld bead must be chipped & peened.
1. The thinner the material, the more difficult the application. 2. ⅛″ thick metal minimum for fillet welds, ¼″ thick metal minimum for gas-tight welds. 3. Preheating of metal to 250–400°F necessary for complicated welds or thick pieces. 4. Joints to be tack welded. 5. Experience necessary for good welds. 6. In multipass welding flux must be cleaned after every weld; all flux must be cleaned after welding. 7. Weld soundness & smoothness of surface not as good as other arc-welding methods.
1. Flux & slag must be cleaned. 2. Not as good as gas welding where concentrated heat can be tolerated, or where easily finished bead is desired. 3. Not recommended where very good properties of welds are required, or where minimum general heating is required.
1. Flux & slag must be cleaned. 2. Joints are painted with flux on both sides and filler rod is dipped in flux. 3. To control heat the torch is moved towards & away from the work. 4. For sections ⅜″ thick or more, pieces should be preheated to temperature of 600–700°F & maintained during welding.
1. High-frequency energy is needed to start the arc, and keep it going. 2. Equipment must be designed especially for this type of welding. 3. Strict cleanliness is important in joint preparation; wire brushing is sometimes necessary to eliminate heavy oxides. 4. Preheating from 400°–800°F is advantageous. 5. In hand welding, the arc must be kept short to ensure complete gas envelopment of weld.
1. Correct arc length is important in eliminating porosity. 2. Strict cleanliness in joint preparation is important. 3. Operator must be trained to produce good welds.
Gas shield process: electronic timers are necessary to prevent studs from piercing the thin material because of the high heat.
1. Necessitates the use of welders of high capacity to supply large currents. 2. Precise control of energy input to the weld area. 3. Adequate provision must be made to compensate for shrinkage of metal after it cools. 4. To provide for welds of high strength, symmetry, & consistency, the oxide must be removed. 5. Alclad alloys are difficult to spot weld for the contacting interfaces of the control alloy tend to decrease weld strength consistency. 6. Cracks and porosity are developed in high tensile alloys; spot welds are often attacked by corrosion. 7. Low alloys show more surface indentation & sheet separation with inconsistent weld strengths. 8. Variation in strength between welds should be not more than 10% ± in 21 of 25 consecutive spot welds, the remaining 4 welds should show maximum variation not over 20% ±. 9. Weld size variation should not be over 10% ± the average of 15 weld diameters. 10. Penetration should be half way through each sheet (maximum).
1. Projections should be backed up by solid masses of metal. This will leave less tendency to squash before weld is completed.
1. Electronic timing equipment is necessary to provide precise control for highest weld quality. 2. Welding speeds must be controlled to prevent metal from sticking to the electrodes. 3. Electrodes must be cooled & cleaned. 4. Same defects occur in seam welding as in spot welding, see list above.
1. Parts must be perfectly aligned. 2. Dies must be exactly shaped to the contour of the work pieces, and must be spaced accurately. 3. Cost of machinery is from \$5,000–\$100,000; cost of dies from \$400–\$2000, depending on the shape and intricacy of the section.
1. Same comments as for flash welding.
1. Surfaces must be clean and free of foreign material. 2. Process offers best results for non-heat-treatable alloys in the annealed condition. 3. Heat-treatable alloys are weldable only if they are in the annealed temper & later heat treated. 4. High-strength alloys are not recommended for pressure welding. 5. Dies must be precise & joints must be brought together accurately. 6. For optimum welds, deformations of 60–70% are necessary. 7. Joints should be used only when they are normal to any bending load & where loading is low.

TABLE 4-10: STANDARD WELDING PROCESSES FOR ALUMINUM (Concluded)

TYPES OF WELDS	DESCRIPTION OF PROCESS	TYPE OF GAS USED	ALLOYS	FLUX	ELECTRODES	RANGE OF METAL THICKNESS MIN. (ORDINARY PRACTICE) INCH	RANGE OF METAL THICKNESS MAX. INCH
BRAZING	Employs special fluxes and filler mat rial having lower melting points than that of the parent metal which are used to join the parent metal without melting the parts.	—		See below	Not used	—	—
TORCH BRAZING	Is done by dipping the filler rod in flux & melting it into the joint with a torch.	Oxyacetylene or Oxyhydrogen		Filler rod is flux coated or piece is flux coated	Not used	—	—
FURNACE BRAZING	Is done by applying a flux, assembling the parts, and heating up the parts in a furnace to point where just the filler will melt & flow into the joint.	—		Flux & filler material added before work is furnace brazed	Not used	.006	½″
SALT BATH (DIP) BRAZING	Is done by assembling tne parts & dipping them in a flux bath heated to a temperature above the filler's melting point but below the melting point of the parent metal.	—		With filler in place, work is dipped in a flux bath	Not used	—	—
SOLDERING	Is similar to soldering steel, etc. Small parts are soldered with a soldering iron, large parts are soldered with a torch.	—		For flow soldering flux is used, for friction soldering no flux used	Not used	—	—

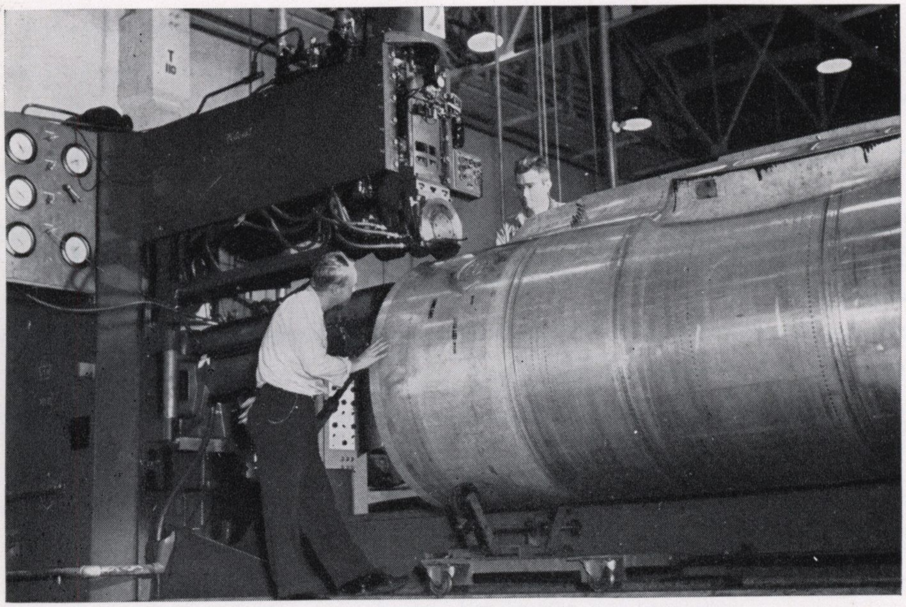


Figure 4-10: This huge seam welder has a throat 60 inches deep, is used to join sections of large external fuel tank designed for aircraft. This Federal Type FCS 3-60-UG universal gear driven unit greatly extends range of seam-welding process.

TABLE 4-11: AVERAGE MECHANICAL PROPERTIES OF BUTT JOINTS MANUALLY HELIWELDED WITH DC STRAIGHT POLARITY, HELIUM, THORIATED-TUNGSTEN ELECTRODES

THICKNESS INCH	AS WELDED TENSILE PSI	HEAT TREATED(1) TENSILE PSI
	6061-T6 Sheet and Plate	
.040 .750	33,400	40,200
	3004-H34 Sheet and Plate	
.125 .250	26,200	.....
	1100-H14 Sheet	
.030 .500	13,140	.....
	3003-F Plate	
1.00	17,500	.....

(1)Heat Treated—Solution Treated at 970 °F Water Quenched—Aged 8 hours at 350 °F

LIMITATIONS, PRECAUTIONS & DISADVANTAGES

1. Joints must be prepared with flux.
2. Assemblies are in annealed condition because of high temperature needed for brazing, not recommended for non heat-treatable alloys.
3. For maximum strength, the assembly should be heat-treated after jointing.
4. Temperature to melt filler should be less than that required to melt part.
5. Select flux so as to prevent excessive attack & irregular flow of filler material.
6. Proper clearance between parts to be joined necessary to assure complete flow of filler material.
7. A small hole should be drilled in hollow members to relieve pressure & distortion.

1. Not used for mass production.
2. Accessibility is necessary for both heating & feeding filler.
3. Flux selected must provide the required temperature indications, (tending to fume or smoke).
4. Assemblies should be hot-water quenched soon after brazing.
5. Remove all flux.

1. Furnace atmosphere must be free from contaminating products of combustion.
2. Temperature must be maintained within ± 5° of specified temperature, range usually 1000–1200°F.
3. Proper cleaning & etching of surface is vital.
4. Chain speed is critical & must be closely controlled.
5. Water quench should follow brazing.
6. Not recommended for joints with wide range of thicknesses.
7. Remove all flux.

1. Preheating is recommended where varied thickness are to be joined (900–1000°F).
2. Cast iron, stainless steel & nickel alloy racks should be avoided due to contamination of the flux.
3. Cleaning, ventilation & continuous heating of the dipping pot is required.
4. Water quenching after brazing & removal of all flux is required.
5. Dipping time from 30 sec. to 3 min.
6. Temperature should be maintained within 5° of specified temperature.

1. Preheat parts from 550–700°F.
2. Applicable for small parts.
3. Oxide must be cleared & kept from re-forming.
4. Not recommended for heat-treatable alloys.
5. All flux should be removed.
6. If moisture is present there is danger of galvanic action, therefore tin-rich or zinc-rich solders should be used.

Thin materials (less than 1/16-inch) are often joined by flanging the sheet and then melting this flange into the joint as filler material. Filler metal in the form of rods is generally required for thicker sections. Flux is required for gas welding.

The most important arc welding processes today are those employing an inert gas shield about the weld pool. These methods produce clean, sound welds in aluminum without corrosive fluxes. Some assemblies cannot be fusion welded any other way because of the impossibility of removing fluxes needed for other methods.

The two monatomic gases, argon or helium, can be used either alone or in combination. With helium, the penetration of the weld is deeper. Therefore it is used to obtain higher welding speeds or where thicker sections are to be welded. Argon, however, finds more general use than helium because it is available commercially with greater purity. Also it provides better control of the weld pool as the metal stays brighter, affording better visibility.

Joint areas must be cleaned completely before

Figure 4-11: Spot welding makes it practical to join formed pieces at a great many points to build strong, rigid, lightweight aluminum structures.

TABLE 4-12: SHEAR STRENGTH OF SPOT WELDS (IN LBS/SPOT) FOR DESIGN WORK

THICKNESS OF EACH OF TWO SHEETS OF EQUAL THICKNESSES INCH	ALLOY WELDED						
	1100-H14 1100-H18	3003-O	3003-H14 3003-H18	5052-O	5052-H34 5052-H38	6053-T4 6053-T6 6061-T54 6061-T6	ALCLAD 2024-T4
0.016	40	40	55	90	90	90	120
0.020	55	55	75	120	120	120	160
0.025	70	70	100	170	170	170	215
0.032	110	110	140	240	240	240	300
0.040	150	140	190	340	340	340	430
0.051	205	180	280	500	510	510	620
0.064	280	250	390	700	720	720	840
0.081	420	340	570	940	1000	1000	1080
0.102	520	480	800	1210	1320	1320	1320
0.125	590	710	1000	1450	1620	1620	1450

Values given in this table are about 65% of average strengths actually obtained.

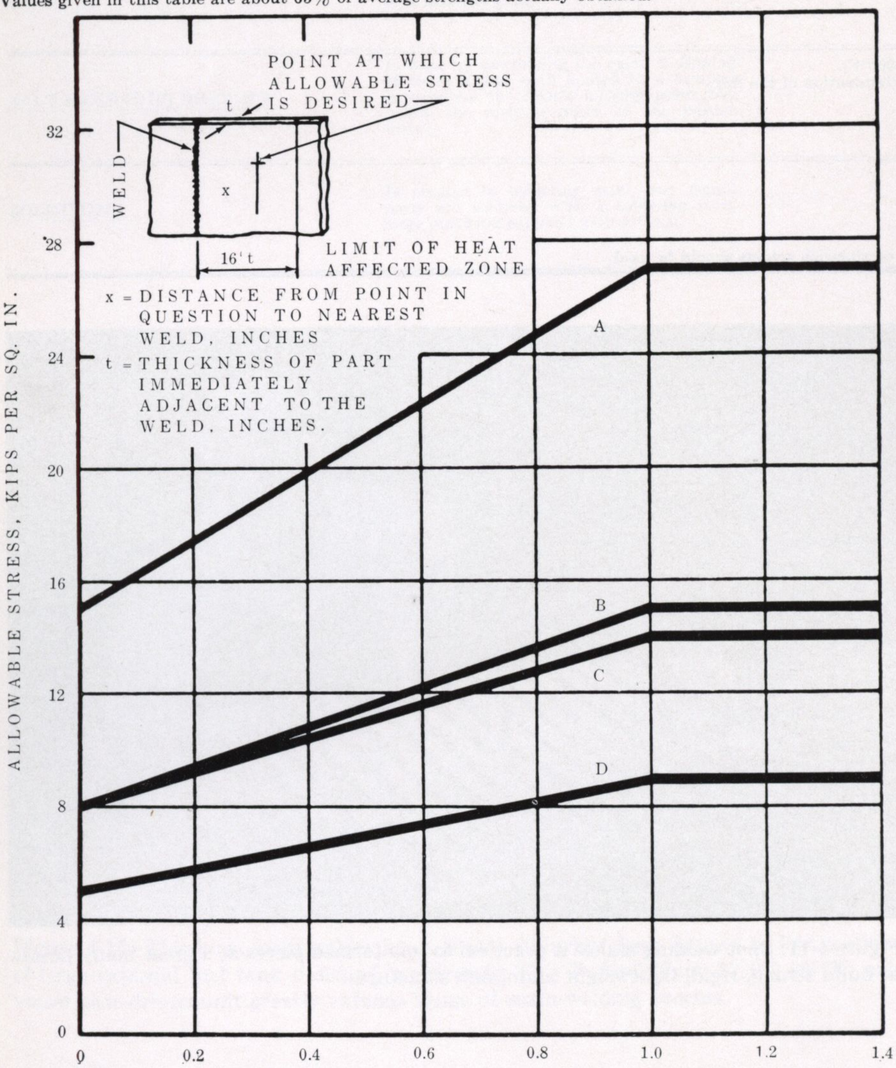


Figure 4-12: Allowable stresses in welded parts.

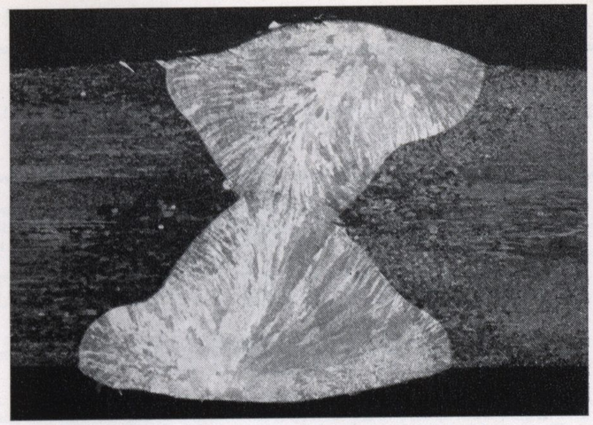


Figure 4-13: Inert-gas-shielded metallic-arc (Aircomatic) weld in ¾-inch thick aluminum plate made in two passes.

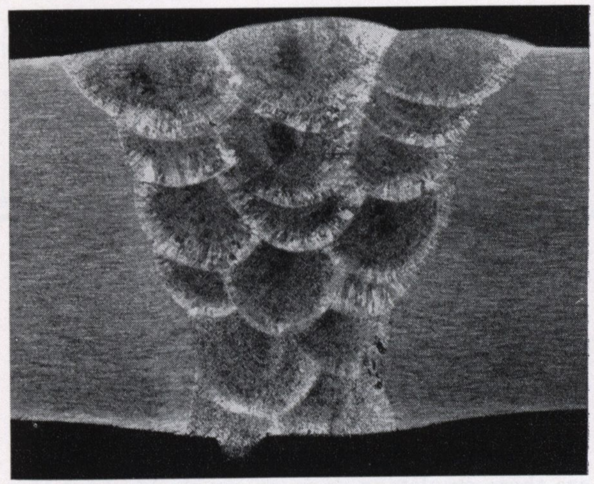


Figure 4-14: Butt weld in 1¼-inch thick aluminum plate made in 17 passes by the inert-gas-shielded metallic-arc (Aircomatic) process.

welding. There is no flux to absorb impurities; the function of the inert gas shield is to prevent the formation of oxides during the welding operations. Sometimes the design of the joint is such as to provide enough parent metal to form the weld bead. Usually though, filler metal is required and may be added either manually in rod form or from a coil of wire when automatic feeds are used.

Inert-Gas-Shielded Tungsten-Arc Welding with non-consumable electrodes is subdivided into two categories: (1) AC Welding; (2) DC Welding. With AC welding equipment there is heat input

TABLE 4-13: AVERAGE MECHANICAL PROPERTIES OF BUTT JOINTS MACHINE HELIWELDED WITH DC STRAIGHT POLARITY, HELIUM, THORIATED-TUNGSTEN ELECTRODES

THICKNESS INCH	AS WELDED TENSILE PSI	HEAT TREATED(1) TENSILE PSI
	6061-T6 Sheet and Plate	
.041	30,600	39,200
.375		
	3004-H34 Sheet and Plate	
.125	27,800	.....
.375		
	1100-H14 Sheet	
.032	13,000	.....
.125		

(1)Heat Treated—Solution Treated at 970° F
Water Quenched—Aged 8 hours at 350° F

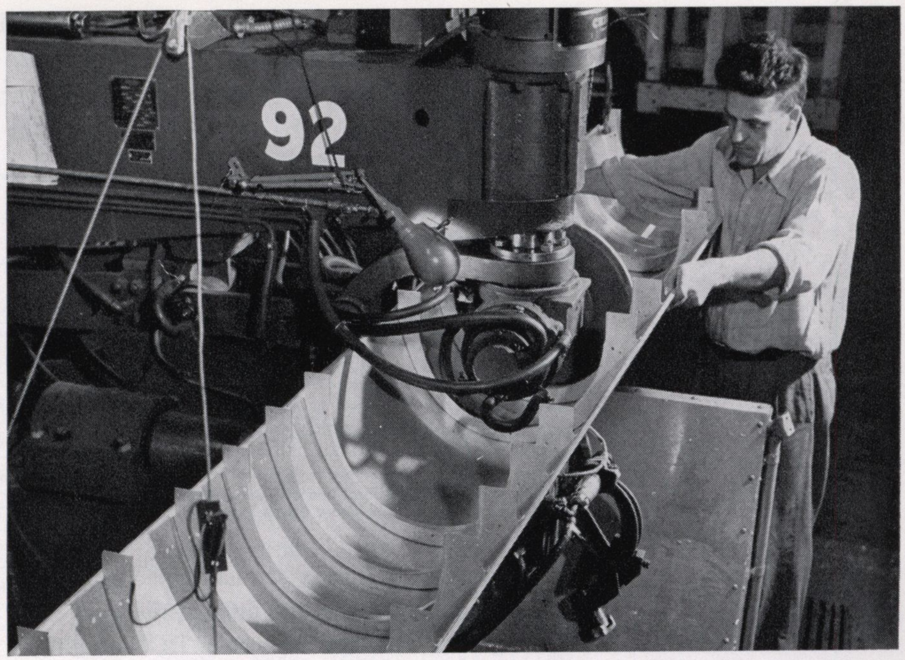


Figure 4-15: Seam welding baffles and stiffeners to the side skin of an aircraft fuel tank. Each tank has 1500 inches of seams, resistance welded at speeds up to 45 inches per minute by rotating the tank in the fixture.

TABLE 4-14: WELDABILITY RATINGS OF ALUMINUM ALLOYS FOR SPOT WELDING

BOTTOM SHEET—NO INDENTATION (LARGE FLAT ELECTRODE)

Top Sheet—Max. or Total Indentation (Domed Electrode)

ALLOY	ELEC. CON. %	HARDNESS*	1100-O			1100-H18			3003-O			2024-O			6053-O			6061-O			2017-O			3003-H14			5052-O			3003-H18			5052-H34			6053-T6			5052-H38			6061-T6			2017-T4			Alclad 2017-T4			2024-T4			Alclad 2024-T4		
SHEET THICKNESS RATIO = t top / t bottom			1/3	1	3/1	1/3	1	3/1	1/3	1	3/1	1/3	1	3/1	1/3	1	3/1	1/3	1	3/1	1/3	1	3/1	1/3		3/1	1/3	1	3/1	1/3	1	3/1	1/3	1	3/1	1/3	1	3/1	1/3	1	3/1	1/3	1	3/1	1/3	1	3/1	1/3		3/1	1/3	1	3/1	1/3	1	3/1
1100-O	59	23	B	A	A	B	D	D	B	A	D	B	D	D	A	A	A	A	A	A	A	D	D	A	A	D	A	D	D	A	D	D	A	D	D	A	D	D	A	D	D	A	D	D	A	B	C	A	B	C	A	B	C	A	B	C
1100-H18	57	44	B	A	A	B	A	A	B	A	B	B	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	D	A	D	D	A	D	D	A	D	D	A	B	C	A	B	C	A	B	C	A	B	C
3003-O	50	28	B	A	A	B	A	A	B	A	A	B	D	D	B	A	A	B	A	A	B	A	D	A	A	A	A	A	D	A	D	D	A	D	D	A	D	D	A	D	D	A	D	D	A	B	C	A	B	C	A	B	C	A	B	C
2024-O	50	42	B	A	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	D	A	A	A	A	A	A	A	A	A	A	A	D	A	D	D	A	D	D	A	D	D	A	B	C	A	B	C	A	B	C	A	B	C
6053-O	45	26	C	B	A	C	B	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	D	B	A	A	A	A	D	A	A	D	A	A	D	A	D	D	A	D	D	A	D	D	A	D	D	A	D	D	A	D	D	A	D	D
6061-O	45	30	C	B	A	C	B	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	D	B	A	A	A	A	D	A	A	D	A	A	D	A	A	D	A	D	D	A	D	D	A	D	D	A	D	D	A	D	D	A	D	D
2017-O	45	45	C	B	A	C	B	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	A	A	A	A	A	A	A	A	A	D	A	D	D	A	D	D	A	D	D	A	D	D	A	D	D	A	D	D	A	D	D
3003-H14	42	35	C	B	A	C	B	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	D	B	A	A	B	A	D	B	D	D	B	D	D	B	D	D	A	D	D	A	D	D	A	D	D	A	D	D
5052-O	40	45	C	B	A	C	B	A	C	B	A	C	B	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	D	B	A	D	B	A	D	B	A	D	A	A	D	A	A	D	A	A	D	A	A	D
3003-H18	40	55	C	B	A	C	B	A	C	B	A	C	B	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	A	A	A	D	A	A	D	A	A	D	A	A	D
5052-H34	40	67	C	B	A	C	B	A	C	B	A	C	B	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	A	A	A	A	A	A	A	A	A	A	A	A	A
6052-T6	40	80	C	B	A	C	B	A	C	B	A	C	B	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	A	A	A	A	A	A	A	A	A	A	A	A	A
5052-H38	40	85	C	B	A	C	B	A	C	B	A	C	B	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	A	A	A	A	A	A	A	A	A	A	A	A	A
6061-T6	40	95	C	B	A	C	B	A	C	B	A	C	B	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	A	B	A	A	A	A	A	A	A	A	A	A	A	A	A	A
2017-T4	30	100	C	C	B	C	C	B	C	C	B	C	C	B	C	B	B	C	B	B	C	B	B	C	B	B	C	A	A	C	A	A	C	A	A	C	A	A	C	A	A	C	A	A	B	A	A	B	A	A	B	A	A	B	A	A
Alclad 2017-T4	..	....	C	C	B	C	C	B	C	C	B	C	C	B	C	B	B	C	B	B	C	B	B	C	B	B	C	B	A	C	B	A	C	B	A	C	B	A	C	B	A	C	B	A	B	A	A	B	A	A	B	A	A	B	A	A
2024-T4	30	105	C	C	B	C	C	B	C	C	B	C	C	B	C	B	B	C	B	B	C	B	B	C	B	B	C	A	A	C	B	A	C	A	A	C	B	A	C	A	A	C	A	A	B	A	A	B	A	A	B	A	A	B	A	A
Alclad 2024-T4	..	....	C	C	B	C	C	B	C	C	B	C	C	B	C	B	B	C	B	B	C	B	B	C	B	B	C	B	A	C	B	A	C	B	A	C	B	A	C	B	A	C	B	A	B	A	A	B	A	A	B	A	A	B	A	A

* Brinell, 500 kg. ld., 10 mm. ball.
Legend: A = Good; B = Fair, difficulties may be encountered under certain conditions; C = Poor; D = Poor, severe indentation and sheet separation must be expected.

TABLE 4-15: RECOMMENDED MINIMUM WELD SPACING, EDGE DISTANCE AND CLEARANCE, IN INCHES

THICKNESS OF SHEETS JOINED INCH	0.016	0.020	0.025	0.032	0.040	0.045	0.051	0.064	0.072	0.081	0.091	0.102	0.125
Minimum edge distance	3/16	3/16	7/32	1/4	1/4	5/16	5/16	3/8	3/8	3/8	7/16	7/16	1/2
Minimum spot spacing	5/16	3/8	3/8	3/8	7/16	7/16	1/2	1/2	9/16	5/8	5/8	3/4	1
Minimum distance between rows of staggered welds	1/4	1/4	5/16	5/16	5/16	5/16	3/8	3/8	7/16	1/2	1/2	1/2	5/8
Minimum overlap, flange width or "flat" required	3/8	3/8	7/16	1/2	1/2	5/8	5/8	3/4	3/4	3/4	7/8	7/8	1
Minimum unobstructed area required to place a weld, diameter	7/16	9/16	9/16	11/16	11/16	11/16	11/16	11/16	11/16	11/16	15/16	15/16	15/16

NOTE: In case of combinations of uneven thicknesses, the thickness of the next to the heaviest gauge joined is to be considered as the thickness governing. All above dimensions are in inches.

to the work only during one-half cycle of current. It may become necessary to preheat the work when welding thick sections. The use of DC, straight polarity current provides a "hotter" arc than that obtained with AC. At one time DC could not be used because the tungsten electrode would melt and contaminate the weld pool. But the development of thoriated tungsten electrodes has eliminated this difficulty.

With the hotter, more concentrated arc, quick melting of the base metal and excellent penetration are achieved with the DC arc. It is not necessary to preheat before welding, even in heavy sections. Narrower, deeper-penetrating weld beads are obtained, and less plate-edge preparation is necessary. Welding is faster, not only because the arc is hotter, but also because vees and grooves can be eliminated or reduced in size so that less filler metal is required. The tendency toward distortion in the weld area is less because there is less total heat input with the DC method.

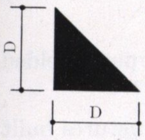
INERT-GAS-SHIELDED METAL-ARC WELDING is similar to inert-gas-shielded tungsten-arc welding process except that the tungsten electrode, which is not consumed in the arc, is replaced by a consumable metal electrode. With the metal arc, thermal efficiency is increased because the transfer of electrode metal to the work carries with it the heat used to melt the electrode, permitting very rapid welding. Either a manually operated welding gun or an automatic head can be used. The gun is suitable for welding in all positions whereas the automatic head is limited to flat or horizontal fillet welding.

RESISTANCE WELDING employs an electric current which is conducted through the parts to be joined. Heat is generated at the juncture of the two parts due to the resistance to the passage of the heavy current. When combined with pressure applied by associated equipment, fusion is produced.

SPOT AND SEAM WELDING are most important in fabricating the aluminum alloys, especially the high-strength heat-treated sheet alloys which can be joined by these processes with practically no loss in strength. Spot welding is widely used to replace riveting, joining sheet structures at intervals as required. Seam welding is merely spot welding with the spots spaced so closely that they overlap to produce a gas-tight joint where desired. The inherent characteristics of aluminum alloys make it necessary to employ spot-welding procedures differing somewhat from conventional practice. Aluminum alloys have an electrical conductivity much higher than most materials commonly spot welded. This necessitates larger welding currents and machines of greater capacity.

When designing joints for spot and seam welding,

TABLE 4-16: ALLOWABLE LOAD (IN POUNDS) ON FILLET WELDS FOR 6061-T6 STRUCTURES WITH 4043 FILLER ROD. P = 2,830DL



Based on 4,000 psi
Shear on throat = 2,830 psi

D = weld size in inches
L = weld length in inches
$P_{allowable}$ = allowable load in lbs

Based on ASCE code for structures of 6061-T6 assembly alloys

L \ D	1/16	1/8	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	3/4	7/8	1
0.5	88	177	265	354	442	531	619	708	796	884	1061	1238	1415
1.0	177	354	531	708	884	1061	1238	1415	1592	1769	2123	2476	2830
1.5	265	531	796	1061	1327	1592	1857	2123	2388	2653	3184	3714	4245
2.0	354	708	1061	1415	1769	2123	2476	2830	3184	3538	4245	4953	5660
2.5	442	884	1327	1769	2211	2653	3095	3538	3980	4422	5306	6191	7075
3.0	531	1061	1592	2123	2653	3184	3714	4245	4776	5306	6368	7429	8490
3.5	619	1238	1857	2476	3093	3714	4333	4953	5572	6190	7429	8667	9905
4.0	708	1415	2123	2830	3538	4245	4953	5660	6368	7075	8490	9905	11320
4.5	796	1592	2388	3184	3980	4776	5572	6368	7163	7959	9551	11143	12735
5.0	884	1769	2653	3540	4422	5306	6191	7075	7959	8844	10613	12381	14150
5.5	973	1946	2918	3891	4864	5837	6810	7783	8755	9728	11674	13619	15565
6.0	1061	2123	3184	4245	5306	6368	7429	8490	9551	10613	12735	14858	16980
6.5	1150	2299	3449	4599	5748	6898	8048	9198	10347	11497	13796	16096	18395
7.0	1238	2476	3714	4953	6191	7429	8667	9905	11143	12381	14858	17334	19810
7.5	1327	2653	3980	5306	6633	7959	9286	10613	11939	13266	15919	18572	21225
8.0	1415	2830	4245	5660	7075	8490	9905	11320	12735	14150	16980	19810	22640
8.5	1503	3007	4510	6014	7517	9021	10524	12028	13531	15034	18041	21048	24055
9.0	1592	3184	4776	6368	7959	9551	11143	12735	14327	15919	19103	22286	25470
9.5	1680	3361	5041	6721	8402	10082	11762	13443	15123	16803	20164	23524	26885
10.0	1769	3540	5310	7075	8843	10613	12381	14150	15919	17688	21225	24763	28300
10.5	1857	3714	5572	7429	9286	11143	13000	14858	16715	18572	22286	26001	29715
11.0	1946	3891	5837	7783	9728	11674	13619	15565	17511	19456	23348	27239	31130
11.5	2034	4068	6102	8136	10170	12204	14238	16273	18307	20341	24409	28477	32545
12.0	2123	4245	6368	8490	10613	12735	14858	16980	19103	21225	25470	29715	33960
13.0	2299	4599	6898	9198	11497	13796	16096	18395	20694	22994	27593	32191	36790
14.0	2476	4953	7429	9905	12381	14858	17334	19810	22286	24763	29715	34668	39620
15.0	2653	5306	7959	10613	13266	15919	18572	21225	23878	26531	31838	37144	42450

it is essential to provide work faces that can be placed in the machine normal to the axis of the electrodes. The work should not touch any uninsulated part of the machine. The distance from the edge of the assembly must be less than the throat depth of the machine. To prevent the occurrence of "edge expulsion" (molten metal squirting out from the joint), the weld must not be too close to the edge. Table 4-15 shows recommended minimum weld spacing, edge distance, and clearance in inches for spot welds. Table 4-12 shows the shear strength of spot welds which may be used for design.

It is advisable in spot welding assemblies of three or more sheets that the thickness ratio of the

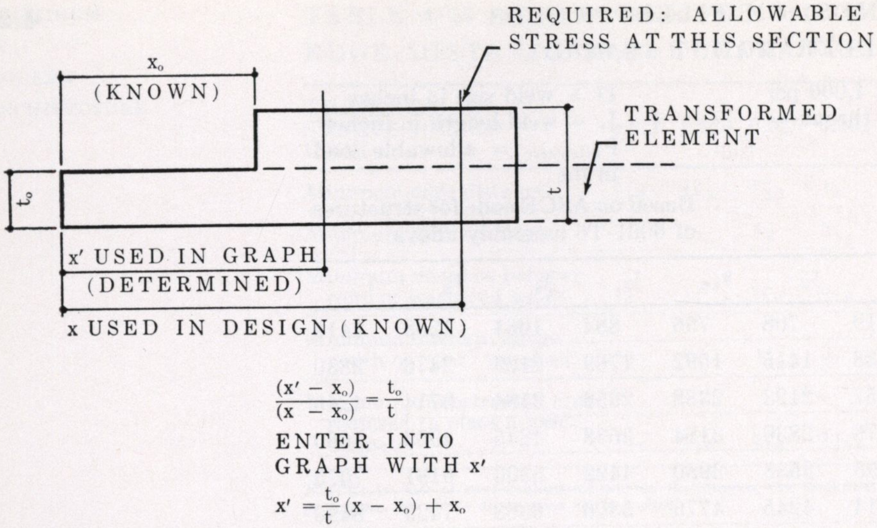


Figure 4-16: Determination of Transformed Distance.

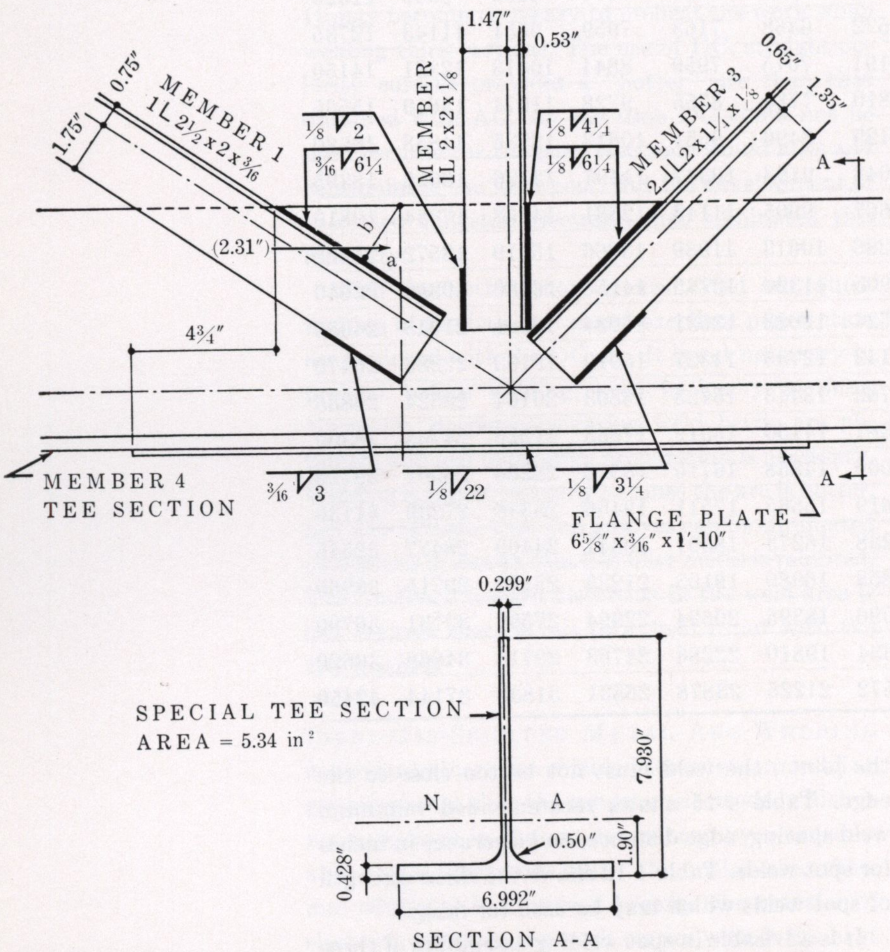


Figure 4-17: Typical welded joint design in aluminum. See Example 4-2, Page 99.

thickest sheet to the thinnest outer sheet in the combination should not exceed 3:1. Spot and seam welding are limited to those elements of an assembly which can be fabricated in the shop.

Figures 4-22 and 4-23 show some typical welded joint details.

The ASCE Code is applicable to structures built of aluminum alloy 6061-T6 wherein welding may be used, subject to certain limitations. The welding must be either by the arc or resistance welding process. Filler material of aluminum alloy 4043 is usually used, although other alloys may be used subject to approval and qualification tests. Flux may not be used. Preheating of the weld joint is allowed, provided the temperature does not exceed 400 °F for a total of 30 minutes.

Standard methods of design are followed, but with the provision that the allowable stresses in the heat-affected zone be modified in accordance with the curves of Figure 4-12. This graph is reproduced from the ASCE Code and is used to determine allowable stress on a plate of constant thickness at any distance from weld. At a distance equal to 16 times the plate thickness, the allowable stress equals the basic working stress.

This graph can be used also for sections which are composed of plate elements of different thicknesses. For this purpose, the section is transformed into one of constant thickness equal to the thickness immediately adjoining the weld. The distance to be used in the graph is the sum of the distances measured along the element adjacent to the weld and a transformed distance. This transformed distance is to the actual distance as the thickness adjacent to the weld is to the thickness of the element under consideration. This interpretation is based on the fact that the total heat absorption is in proportion to the volume of the parent metal. On this basis, shapes composed of elements of non-uniform thickness can also be transformed to plate sections of constant thickness, which can be used with the graph. Figure 4-16 illustrates the concept of the transformed section.

Allowable Loads on fillet welds are listed in Table 4-16. Butt welds are considered to have the same strength as the structure alloy modified by the

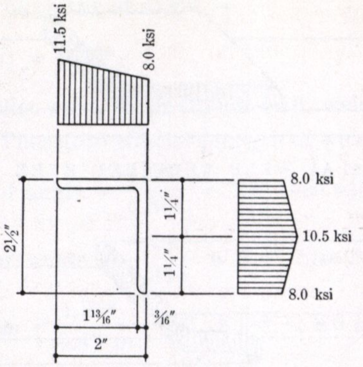


Figure 4-18: Allowable stresses for Member 1.

curves of Figure 4-12 for the heat-affected area. Therefore the strength of the butt weld can never exceed the minimum values as set forth in these curves.

EXAMPLE 4-2:

Problem: To determine the required fillet welds for the welded joint shown in Figure 4-17.

Assumed assembly alloy is 6061-T6. Filler rod alloy is 4043 (ASCE Code). Welding to be accomplished by either the inert-gas-shielded tungsten-arc or the inert-gas-shielded metal-arc welding processes.

Fillet welds required to join Member 1 (one angle $2\frac{1}{2} \times 2 \times \frac{3}{16}$*) to stem of tee:*

$P = -4.44^{K}$

Stress through back of angle =

$$\frac{1.75}{2.50}(4.44) = 3.11^{K}$$

Stress through toe of angle =

$$\frac{0.75}{2.50}(4.44) = 1.33^{K}$$

Use $\frac{3}{16}''$ fillet weld. From Table 4-16, weld value = 531#/in. Therefore effective length of weld required

$$\text{At back of angle} = \frac{3.11}{0.531} = 5.8''$$

$$\text{At toe of angle} = \frac{1.33}{0.531} = 2.5''$$

Allow approximately ¼″ for formation of crater at end of weld. Therefore use:

At back of angle — 6¼″

At toe of angle — 3″

Check allowable load on angle due to reduction of allowable stress in heat-affected zone: Figure 4-18 shows the allowable unit stress distribution over the cross section of Member 1. (allowable stresses taken from Figure 4-12). At weld: maximum allowable stress in compression = 8.0 ksi.

At distance "x" from weld stress is determined

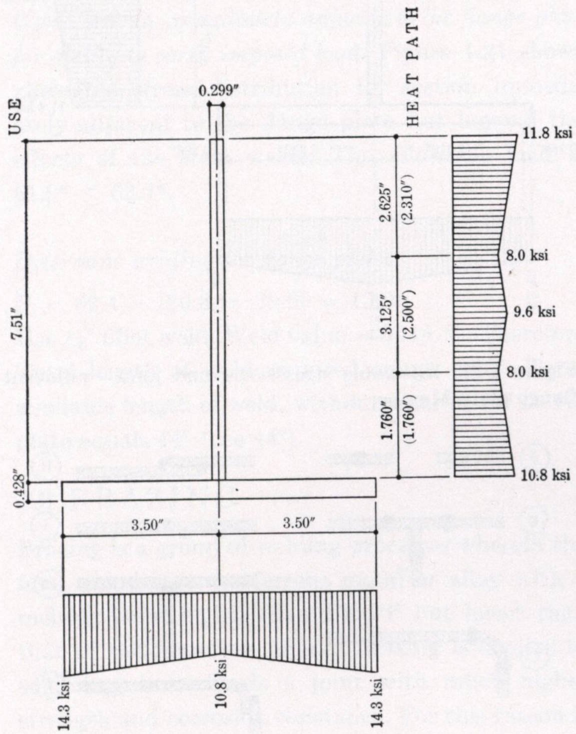


Figure 4-19: Allowable stresses (@ Joint) Member 4.

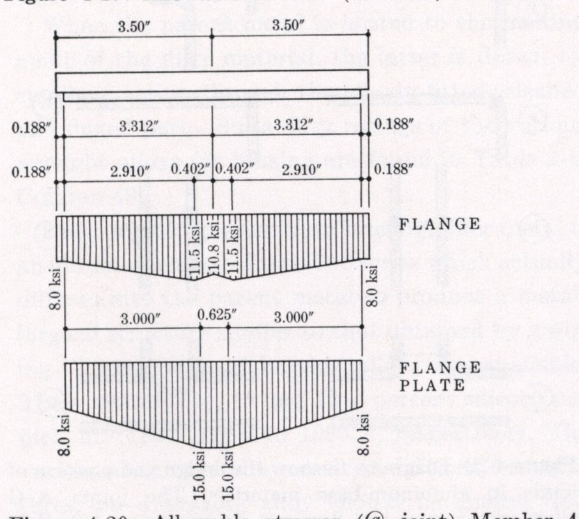


Figure 4-20: Allowable stresses (@ joint) Member 4 with flange (stem not shown).

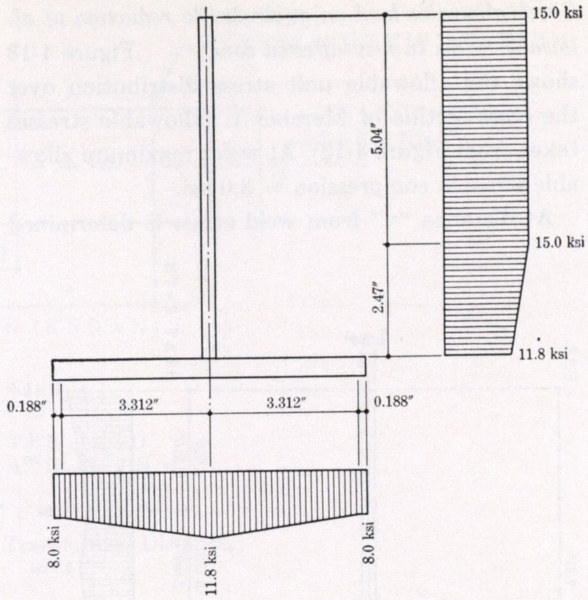


Figure 4-21: Allowable stresses beyond joint—adjacent flange plate Member 4.

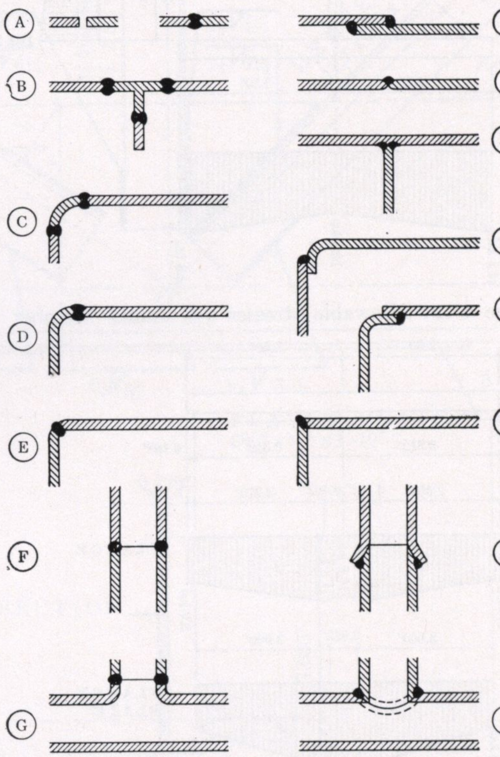


Figure 4-22: Diagrams to show the design and position of joints in aluminum-base materials. The joints A–G allow easy removal of flux and are recommended when flux is used to make a joint.

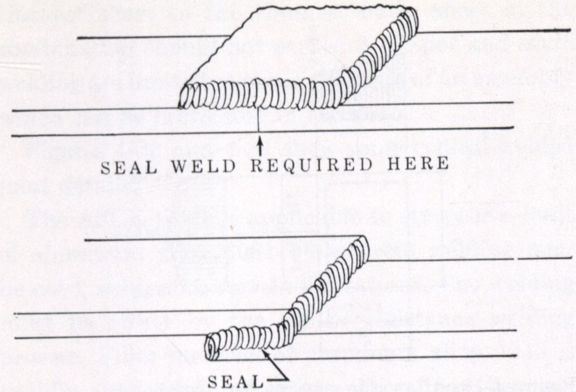


Figure 4-23: Diagrams to illustrate the sealing of lapped joints, essential in welding aluminum when flux is used.

(from Figure 4-12) depending on ratio $\frac{x}{16t}$ where "t" is the thickness of piece welded.

Allowable load = sum of allowable unit stresses times unit areas.

At toe of outstanding leg "x" = $1\frac{13}{16}''$ and $\frac{x}{16t} =$ 0.60. Therefore allowable compression stress = 11.5 ksi. Midway between welds, at long leg, x = $1\frac{1}{4}''$ and $\frac{x}{16t} = 0.41$. Therefore allowable compression stress = 10.5 ksi.

Allowable load =

$$[8.0(2\tfrac{1}{2}) + \frac{2.5}{2}(2\tfrac{1}{2}) + 8.0(1\tfrac{13}{16}) + \frac{3.5}{2}(1\tfrac{13}{16})](\tfrac{1}{8})$$
$$= 5.10^{K}$$

Member satisfactory since $5.10^{K} > 4.44^{K}$

The full analysis for determining the reduced allowable load of this member was undertaken to demonstrate the procedure to be followed. The unit stress in this member $= \frac{\text{load}}{\text{area of member}} = \frac{4.44^{K}}{0.82\text{ in.}^2} =$ 5.42 ksi.

The allowable unit stress immediately adjacent to the weld equals 8.0 ksi > 5.42 ksi.

Fillet welds required to join Member 2 (one angle 2 x 2 x $\frac{1}{8}$*) to stem from tee:*

$P = -1.85^{K}$

Stress through back of angle =

$$\frac{1.47}{2.00}(1.85) = 1.36^{K}$$

Stress through toe of angle =

$\frac{0.53}{2.00}(1.85) = 0.49^{K}$

Use 1/8″ fillet weld. From Table 4-16, weld value = 354#/in. Therefore effective length of weld required

At back of angle $= \frac{1.36}{0.354} = 3.8''$ (use $4\frac{1}{4}''$)

At toe of angle $= \frac{0.49}{0.345} = 1.4''$ (use 2″)

Unit stress $= \frac{1.85^{K}}{0.49 \text{ in.}^2} = 3.78 \text{ ksi} < 8.0 \text{ ksi}$

Fillet welds required to join Member 3 (two angles 2 x 1½ x 1/8) to stem of tee:

$P = +6.10^{K} \quad P/2 = +3.05^{K}$

Stress through back of angle =

$\frac{1.35}{2.00}(3.05) = 2.06^{K}$

Stress through toe of angle =

$\frac{0.65}{2.00}(3.05) = 0.99^{K}$

Use 1/8″ fillet weld. From Table 4-16, weld value = 354#/in. Therefore effective length of weld required

At back of angle $= \frac{2.06}{0.354} = 5.8''$ (use $6\frac{1}{4}''$)

At toe of angle $= \frac{0.99}{0.354} = 2.8''$ (use $3\frac{1}{4}''$)

Unit stress $= \frac{3.05^{K}}{0.390 \text{ in.}^2} = 7.82 \text{ ksi} < 8.0 \text{ ksi}$

Check allowable load on Member 4 due to reduction of allowable stress in heat-affected zone:

$P = +62.4^{K}$

Figure 4-19 shows the allowable unit stress distribution over the cross section of Member 4 (at section *a*).

The allowable load is determined as previously with Members 1, 2 and 3 with the modification for the different thicknesses of the flange and the stem.

Allowable load $= 58.4^{K} < 62.4^{K}$

Add a flange plate at the joint to increase the area. Figure 4-20 shows the resultant allowable stress distribution in the flange and the flange plate. The allowable stress distribution in the stem is not affected by the addition of the flange plate and therefore is not shown. The allowable loads for each component of the tee and flange plate is:

Stem	$= 20.8^{K}$
Flange	$= 29.6^{K}$
Flange Plate	$= 15.6^{K}$
Total	$= 66.0^{K} > 62.4^{K}$

Check section immediately adjacent to the flange plate for ability to carry imposed load: Figure 4-21 shows allowable stress distribution for section immediately adjacent to the flange plate but beyond the effects of the stem welds. The allowable load is $61.9^{K} < 62.4^{K}$.

Determine welding for flange plate:

$P = 62.4 - [20.8 + 29.6] = 12.0^{K}$

Use 1/8″ fillet weld. Weld value = 354#/in. Therefore Total length of weld required equals 33.9″. Total available length of weld, without returns, for 1′–10″ plate equals 44″ (use 44″).

4.3 BRAZING

Brazing is a group of welding processes wherein the filler metal is a non-ferrous metal or alloy with a melting point higher than 1000°F but lower than that of the materials joined. Brazing is similar to soldering, but affords a joint with much higher strength and corrosion resistance. For this reason it is sometimes called "hard soldering."

When the parent metal is heated to the melting point of the filler material, the latter is drawn by capillary action through the closely fitted, cleaned and fluxed parts. Suitability ratings of the various wrought alloys for brazing are found in Table 2-4, Column 49.

Filler Metal: In aluminum brazing, filler metal is an aluminum alloy of the 4000 series which actually diffuses into the parent metal to produce a metallurgical structure similar to that obtained by welding. Three types of brazing alloys are available. They contain 7½, 10 and 12½ percent silicon, and melt at 1180, 1110 and 1060°F, respectively. The various aluminum alloys melt at different temperatures. So a brazing alloy should be chosen that provides sufficient difference in melting temperature

between parent metal and filler material. Otherwise it will be difficult to avoid melting the parent metal. When brazing sheet is used, no filler metal is applied during brazing.

Fluxes: Brazing of aluminum has been made possible by the development of fluxes which melt below the brazing temperature and not only prevent oxidation but also react on the aluminum oxide film to permit the filler metal to wet and bond to the underlying base metal. Brazing fluxes consist of various combinations of certain fluorides and chlorides. They are supplied in dry powder which is dissolved in distilled water to form a paste. Those having the lowest melting point combined with greatest chemical action produce maximum flow of the brazing metal. They should be used with temperatures below 1100°F. These are primarily intended for torch brazing or for alloys with poor brazing characteristics. Less active fluxes with medium to high melting points are intended primarily for furnace brazing of high purity aluminum 1100, 3003 or clad brazing sheet (see Section 3.6).

Only small quantities of flux should be used as it may severely attack thin materials. Besides, too much flux results in irregular flow of filler material. Brushing, dipping or spraying may be used to apply the flux to the work. Each method requires a different mix.

Where filler material is to be prevented from flowing in a certain direction, commercial stop-off compounds are available which may be applied as a paste and then brushed off after brazing. If jigs and fixtures are used, stop-off compounds may be baked onto them to last for several brazing cycles.

Characteristics: Brazed joints will show a strength of approximately 14,000 psi while welded joints will run considerably higher. Brazed joints make more economical use of filler metal than welded joints. They can be made faster and have a neater appearance, requiring little finishing work, if any. Brazing makes possible the joining of extremely thin sections to each other or to thicker parts. Due to the capillary action, the furnace brazing process is particularly useful for inaccessible joints. The corrosion resistance of brazed joints is in general comparable to that of welded joints.

Effect of Brazing on Strength of Assemblies: Because brazing temperatures (approximately 1100°F) are above annealing temperatures (650–800°F), the brazed assembly will normally be in the annealed condition. Where maximum strength is required, a heat-treatable alloy should be selected. The assembly can be heat treated after joining by quenching directly from the brazing temperature or from the solution heat-treating temperature (910–980°F).

A fast method of confining the annealed material to only a small area where the heating will have the least effect on the assembly is the application of induction or resistance brazing whereby the heating effect is localized to a minimum. However, such close temperature control requires electronic equipment, the cost of which may necessitate large production quantities.

Brazing Designs: The use of fillet joints is recommended. These facilitate the production because their smooth, uniform surface needs no grinding to remove excess metal (see Figures 4-24, 4-25 and 4-26).

The most important single factor in joint design is complete penetration of filler metal throughout the joint. Lap joints, T-joints and lock seam joints should be employed wherever possible. In lap joints, the lap should be about 4 times the thickness of the thinnest member. With lock-seam joints, care should be used to provide sufficient clearance for proper flow of the brazing alloy into the joint.

Bending up sheets at adjoining edges to form two short almost parallel flanges has proved satisfactory, especially if there is a small angle between the flanges to aid the flow of molten metal into the joint and the flushing out of flux.

As the joint should be cleaned after brazing, it is essential to provide an exit for flux after it completes its work. Proper clearance is of great importance to assure flow of metals throughout all portions of the joint. Pressed fits can be used provided they are not so long or deep as to entrap flux, and provided they permit fillets to be formed at the ends.

Wherever a hollow member is to be completely sealed, a small hole should be drilled to serve as a relief vent. This will prevent distortion or collapse of the assembly by air pressure. The hole may be

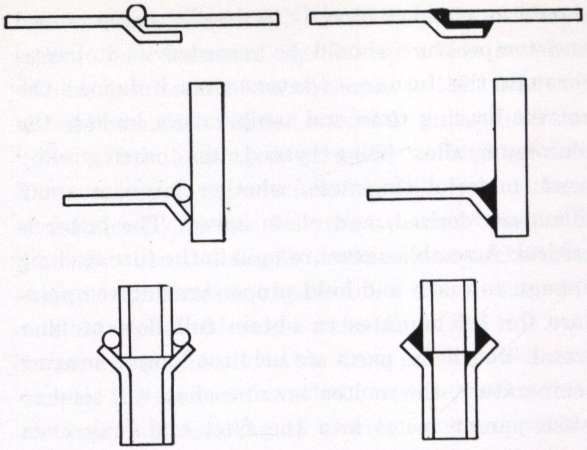


Figure 4-24: These three before-and-after diagrams show how properly placed brazing alloy will be drawn through the entire joint by capillary attraction to form smooth fillets and good solid joints.

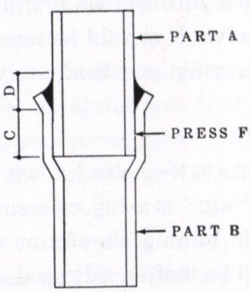


Figure 4-25: This brazed tubing joint prevents brazing flux from entering the system. The press fit at "C" is tight enough to hold 5-20 pounds air pressure before brazing, confining brazing alloy and flux to area "D". Neither alloy nor flux enters area "C".

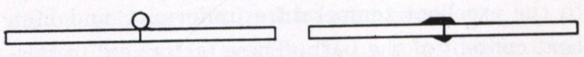


Figure 4-26: Improperly designed joint causes excess of molten brazing alloy to remain on surface, requiring finishing operations. Properly designed joints have fillets which eliminate this trouble.

sealed later by torch brazing.

Aluminum may be brazed by a number of methods, differing mainly in the way that heat is applied to the work. These include torch brazing, salt bath brazing and resistance brazing.

It is essential that the surfaces be thoroughly cleaned prior to brazing. For 1100 and 3003 alloys, degreasing is usually sufficient, while for the other alloys an etching treatment is recommended.

Torch Brazing is employed when the joints are accessible both for heating with the torch flame and for feeding filler metal into the joint. Inaccessible joints must be brazed by furnace or salt bath methods. Filler metal is usually in the form of a rod as in torch welding.

The oxyacetylene flame is preferred for brazing because its temperature is around 6300°F. Its high heat output permits bringing the work up to temperature faster, speeding the brazing operation. Also the heat can be concentrated better, aiding control. While other gases are satisfactory, they are slower and are used mainly in preheating to increase production.

Flux is applied either by brushing, or by a filler rod. If the rod is used, it is dipped into the flux, or it is flux coated.

Since aluminum shows no color when hot, it is necessary to have some means for determining when the parts are reaching the brazing temperature. The flux selected should be one that provides the required temperature indications. As the work comes up to temperature, the liquid flux will first dry out. Then as more heat is added, it will melt and flow freely. Just as the brazing temperature is reached, it will tend to fume or smoke slightly. That is the temperature indication beyond which parts must not be heated, or melting will result.

When brazing 5052 and 5056, the oxide coating must be mechanically abraded with the rod while at heat and covered with flux to break through the tough oxide coating on these alloys.

Aluminum brazing alloys are more viscous than other brazing materials, a distinct advantage where gaps must be bridged. Also aluminum brazing alloys tend to surface creep or flow because of their intersolubility or tendency to diffuse into the base material. These characteristics reduce torch brazing of aluminum to little more than skillful heating of base metal to melt the brazing alloy which readily flows through all portions of the joint by capillary action.

Non-heat-treatable alloy assemblies are usually

TABLE 4-17: SOLDERS AND FLUXES FOR SOLDERING ALUMINUM

SOLDER	FLUX	MANUFACTURER
"Alumaweld Special"	"Alumaweld All Metal"	Johnson Mfg. Co., Inc. Mt. Vernon, Iowa
"EutecRod 192"	"Eutector 192"	Eutectic Welding Alloys Corp.
"EutecRod 199"	"Eutector 199"	172nd St. & Northern Blvd.
"EutecRod 199B"	"Eutector 199B"	Flushing, New York 58, N. Y.
"EutecRod 19"		
"Allen's Alumi Solder"		L. B. Allen Company 6759 Bryn Mawr Avenue Chicago 31, Illinois
"Gardiner Aluminum Solder"		Gardiner Metal Co. 4838 South Campbell Chicago, Illinois
"All State Aluminum Solder"		All State Welding Alloy Co. White Plains, New York

quenched in hot water to cool the assembly and help loosen and remove the flux. Heat-treatable alloy assemblies should also be quenched in hot water as soon as the filler metal has solidified. Quenching will produce mechanical properties in the heat-treatable alloys similar to the "-T4" temper. Subsequent aging will raise the strength to within the range of the "-T6" temper.

To prevent chemical attack, it is vital that all residual flux be removed from the work. The elimination of usual grinding and chipping operations in finishing up the joint is one of the important advantages of brazing. Most work will require no finishing at all. Just as the silicon used in welding to reduce the freezing point of the weld metal will discolor the weld if it is anodized, so will the silicon in a brazed joint cause discoloration where a brazed member is anodized. In each case the filler metal will turn black.

FURNACE BRAZING: Any continuous mesh-belt furnace designed to operate in the temperature range of 1000–1200°F is suitable for aluminum brazing provided it can maintain constant and uniform temperature, within plus or minus 5°F of the specified temperature, and further, that the furnace atmosphere is free from contaminating products of combustion.

To check furnace temperatures, a thermo-couple should be attached directly to the part being brazed and temperature should be recorded as it passes through the furnace. Factors that influence the correct brazing time and temperature include the aluminum alloy being brazed, the brazing alloy used, material thickness, whether large or small fillets are desired, and chain speed. The latter is critical. Assemblies must remain in the furnace long enough to reach and hold proper brazing temperature for 1–5 minutes to obtain full flow of filler metal. Yet, if the parts are held too long at brazing temperature, the molten brazing alloy will tend to wash parent metal into the fillet and may even wash through thin-walled sections.

Depending upon the thickness of the sections to be joined, chain speed and the like, a period of 4–7 minutes will be required to bring them up to brazing temperature. As the assemblies come from the furnace, any residual flux will be found quite hygroscopic and corrosive. It should be removed within 5 minutes after brazing and preferably before final cooling.

SALT BATH BRAZING, also known as "flux dip" brazing, or just "dip" brazing, is assuming increasing importance in joining aluminum assemblies for several reasons. The molten salt used as the heating medium consists of fluorides which also supply the fluxing action, eliminating the need for a separate fluxing operation.

Heating is extremely fast, enabling the entire brazing operation to be completed in 2–5 minutes. Precise temperature control is easy to obtain, due to the excellent temperature uniformity and high heat content of the bath. These factors aid in raising the work quickly to a temperature that melts the brazing alloy, but not the base metal. Actual time in the flux bath will vary from 30–180 seconds. Preheating to about 900°F is recommended where thick and thin sections are to be joined. This will reduce temperature variations and will avoid undue cooling of the bath by the assembly.

The design of joints and the form and location of filler metal have already been discussed. The work is preferably made self-jigging, or jibs are designed so they need not be immersed in the bath. Iron con-

tamination of the bath is a critical factor in brazing aluminum because of the fluxing action required. Where fixtures must be immersed in the bath, they should be made of nickel, monel or pure aluminum.

Salt bath brazing is primarily a high production process. It is especially suitable for making a multiplicity of joints in intricate assemblies, as in joining tubes and fins to produce heat exchangers. Also a large number of assemblies can be brazed in one batch, limited only by the size of the salt bath furnace and the allowable drop in bath temperature as the furnace is loaded. After removing from the bath and draining off as much flux as possible, the work can be quenched immediately as previously described.

4.4 SOLDERING

Soldering employs a bonding alloy, called solder, with a melting point several hundred degrees lower than that of brazing alloys. Conventional soldering methods are not easily applicable to aluminum. The properties of aluminum that necessitate different techniques are its great affinity for oxygen, its high thermal conductivity, and its large coefficient of expansion.

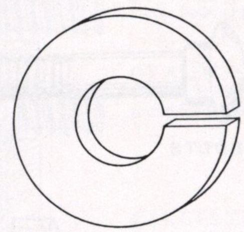
On large parts, the sections adjoining the area to be soldered will conduct heat away so fast that it is difficult to hold the working area at the correct temperature long enough to complete the joint. Distortion also enters the picture due to the larger amount of expansion. The usual soldering temperatures for aluminum are 550–700°F. While most other metals are soldered at 375–400°F, few aluminum solders melt in this latter range.

Small parts can be brought up to soldering temperature with a soldering iron and held there while making the joint. For large parts, a torch is recommended. The practical limit appears to be an area of about 20 square inches for individual sheet metal parts. Sections larger or thicker are not so readily handled.

Most difficulties in soldering aluminum are caused by the great affinity of aluminum for oxygen. Solder will not bond on the glass-like oxide film which is present on aluminum as soon as it is exposed to air. A main objective, therefore, is the

TABLE 4-18: ALUMINUM SPRING LOCK WASHERS

SCREW OR BOLT SIZE	SECTION SIZE
No. 2	.035 x .020
No. 4	.040 x .025
No. 6	.047 x .031
No. 8	.055 x .040
No. 10	.062 x .047
¼″	.109 x .062
5/16″	.125 x .078
⅜″	.141 x .094
7/16″	.156 x .109
½″	.171 x .125
9/16″	.188 x .141
⅝″	.203 x .156
¾″	.234 x .188



removal of this oxide coating prior to tinning. This may be effected in essentially two ways, but prior to applying either of them, the areas to be soldered should be cleaned and abraded so as to render the oxide film as thin as possible.

Ordinarily a suitable flux is applied to dissolve the oxide and prevent it from re-forming . . . or otherwise react so that the solder may bond directly to the underlying aluminum. The flux is also made to fume at the correct soldering temperature to indicate when that temperature has been attained. At this point the flux should be fluid so the solder can easily displace it at the joint. It should produce little or no attack on the aluminum and should be easily removed after soldering.

The second method to get below the oxide film is to mechanically abrade it down through an overlying layer of molten solder, using the soldering iron, a wire brush or other tool.

After the surfaces to be joined have been tinned, they can be soldered together in the usual manner. When soldering aluminum to other metals, it is suggested that the aluminum surfaces be tinned and then joined to the other metal with ordinary lead-tin solder and flux. If any difficulty is encountered, the surface of the other metal should first be tinned.

Since all aluminum solders contain at least two

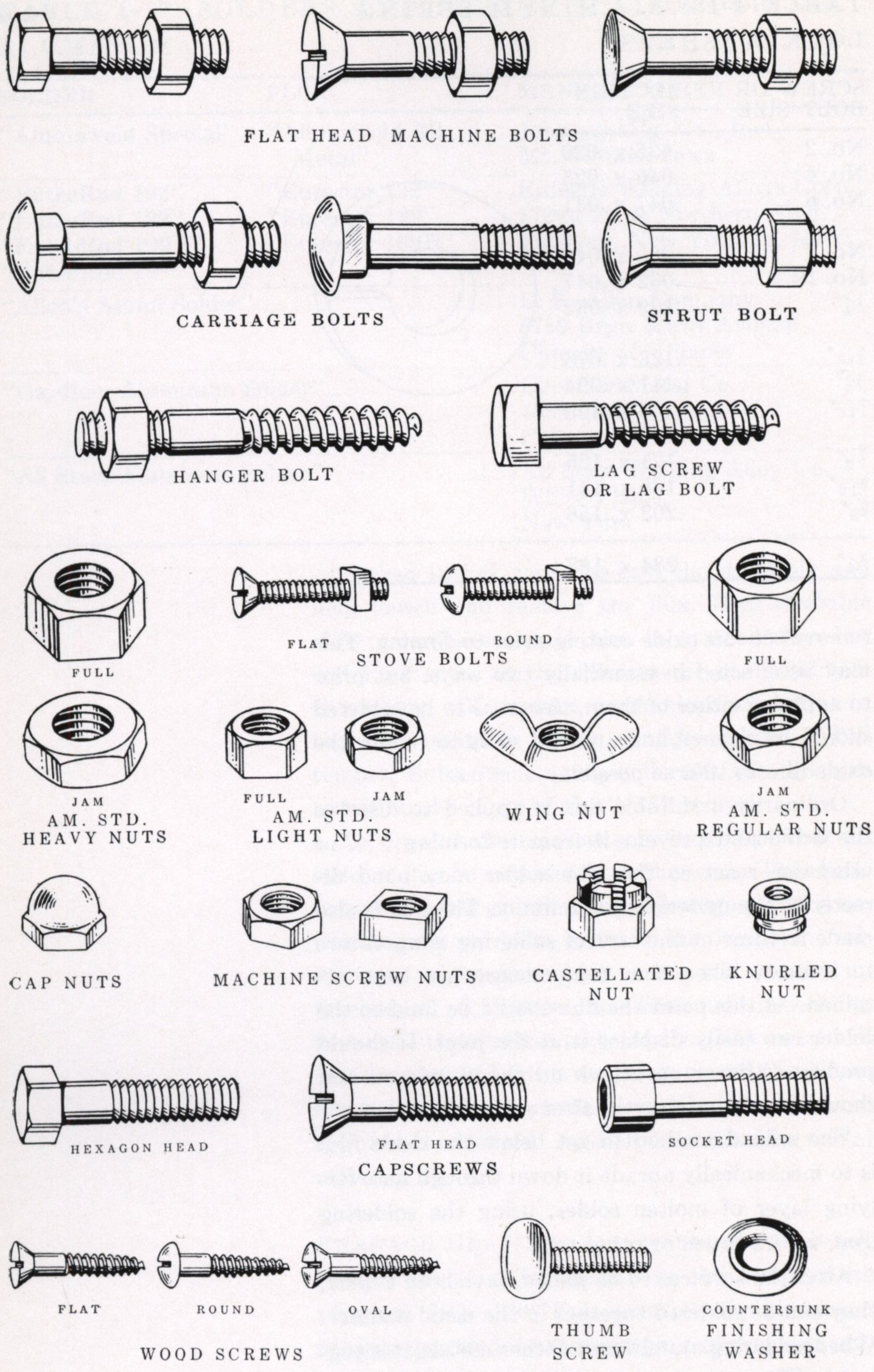


Figure 4-27: Various types of standard screw fasteners. (Concluded in Figure 4-28.)

other metals, electrolytic corrosion may occur in the presence of moisture (see Section 2.4), resulting in holes or pits which may reduce the strength of the joint seriously. Tin-rich solders with considerable zinc content are often preferred because they minimize this action. See Table 4-17.

In corrosive atmospheres a moisture-proof lacquer coating or a paint coating is recommended. Where joints are subject to salt water contact, they may be cathodically protected by attaching strips of zinc or cadmium.

Suitability ratings of the various alloys to soldering are given in Column 50 of Table 2-4.

4.5 SCREW FASTENERS, NUTS AND WASHERS

Aluminum screw fasteners are usually made from alloy 2024 because of its high tensile and shear strengths. Screw fasteners ordinarily are supplied unfinished, semi-finished or finished. To prevent marring, care should be exercised to avoid bringing a roughly finished fastener in contact with a finely finished aluminum surface. These fasteners are available in three weights: regular, heavy, light.

Aluminum bolts and nuts will not seize if anodized or if given an application of molybdenum disulphide suspension in oil or grease; zinc stearate; or a 50–50 mixture of petrolatum and 200-mesh zinc dust.

Lead washers have proved satisfactory not only because they stop electrolytic corrosion as a result of polarization, but also because their softness affords good sealing. They are, however, not recommended in coastal areas, where rubber washers, possibly with an aluminum washer on top, are more advantageous. The rubber-aluminum combination results in good sealing action with adequate mechanical strength.

Table 4-18 lists aluminum lock washers available for use with aluminum screws and bolts. Made of 7075-T6 they compare in hardness and reactive pressure with stainless steel lock washers. Aluminum lock washers are more expensive than steel or cadmium-plated washers but considerably cheaper than stainless steel.

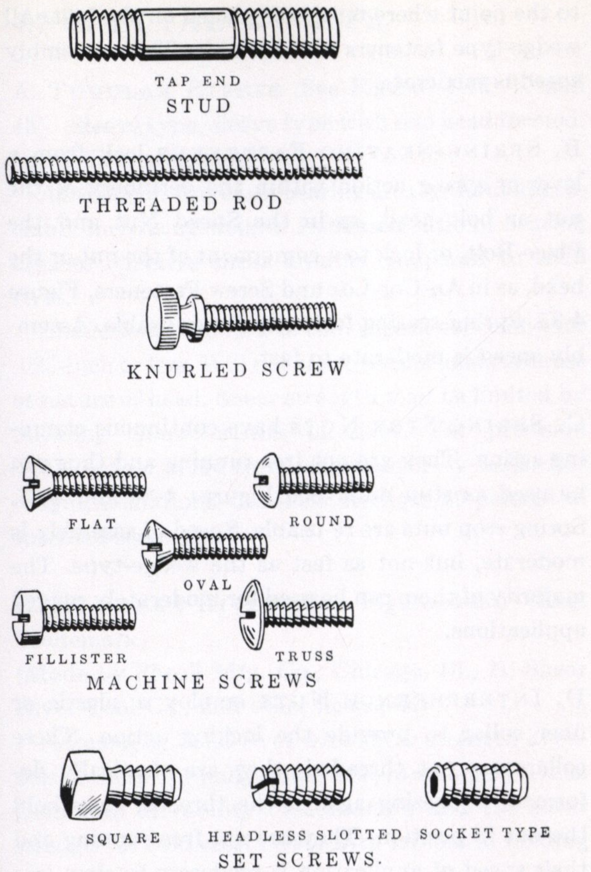


Figure 4-28: Various types of standard screw fasteners.

4.6 PATENTED SCREW FASTENERS

The majority of special screw fasteners aim at supplying a locking action in the fastener itself and thus eliminate the need for a lock washer. Exceptions are the blind and quick-release fasteners (see below). Since the locking action is more easily incorporated in the design of the nut, the majority of these special fasteners are nuts. In all cases the opposite component is a standard part; i.e., for a special nut a standard screw or bolt is employed and vice versa. The following types of special fasteners may be distinguished:

A. WEDGE TYPE FASTENERS are locked by the wedging of one part against the other, Figure 4-34. They are employed where severe stress, shock or vibration must be overcome. They are free-running

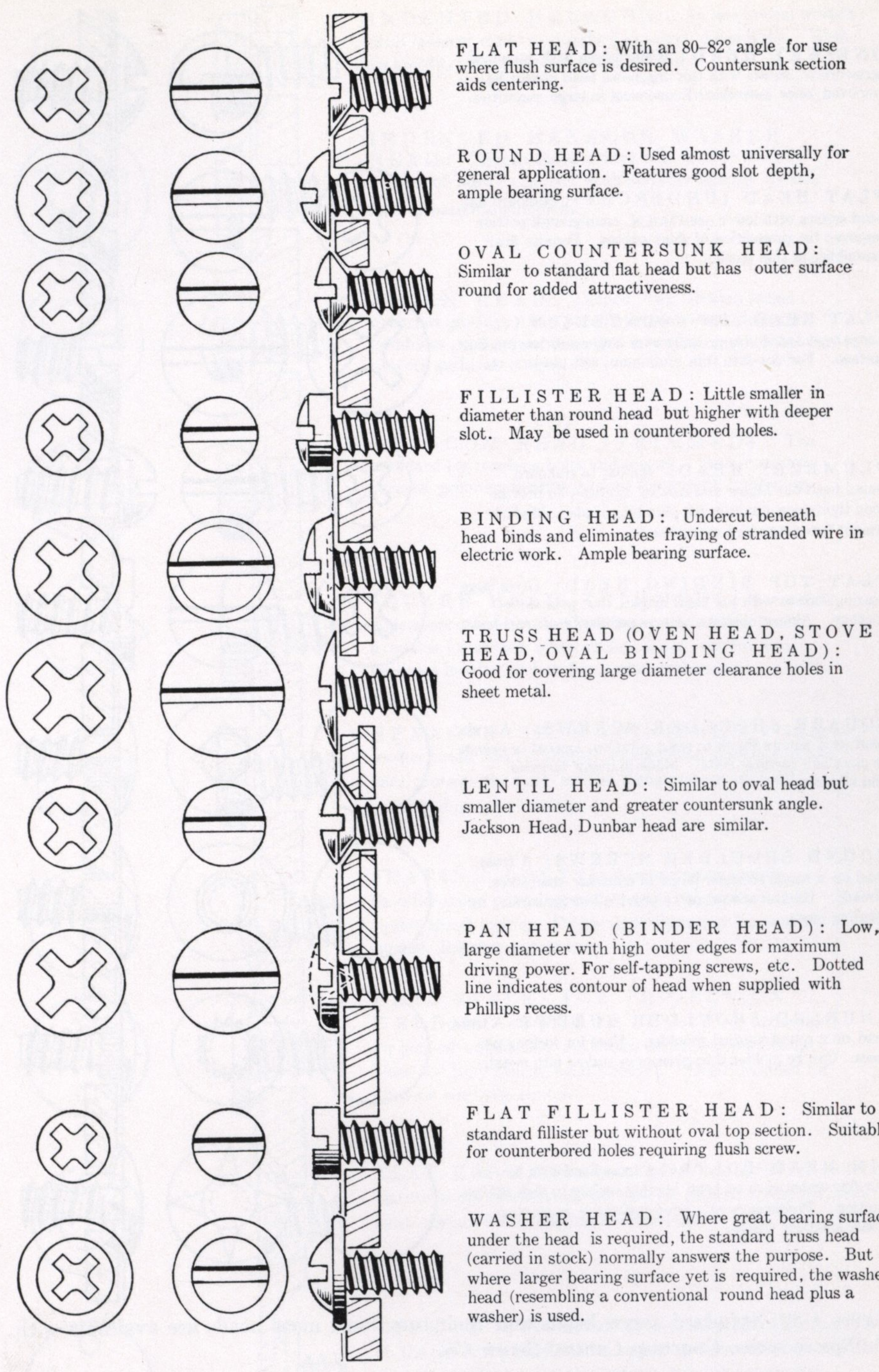


Figure 4-29: Standard screw heads and their functions; most heads are available with Phillips recesses. Courtesy Central Screw Co. (Concluded in Figure 4-30)

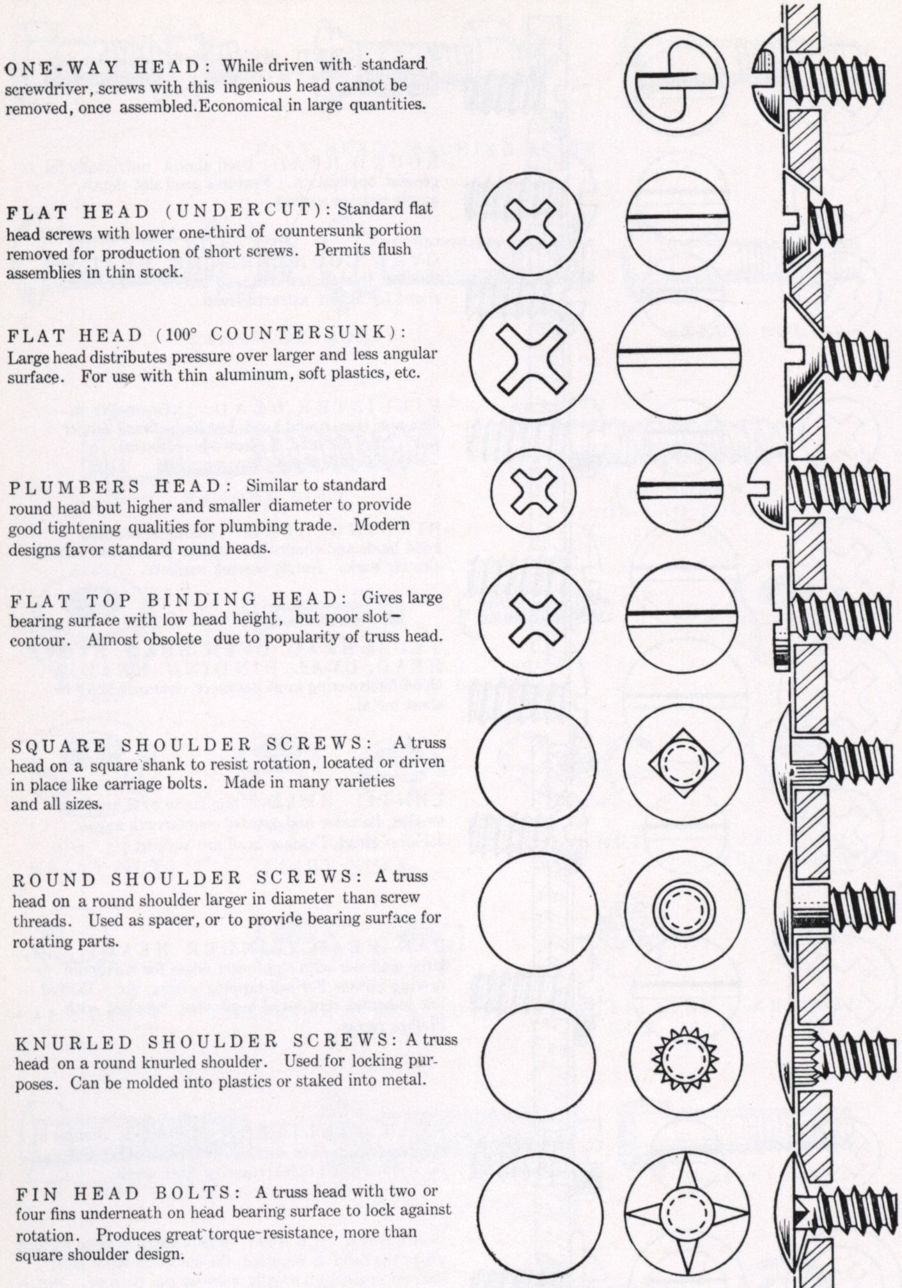


Figure 4-30: Standard screw heads and their functions; most heads are available with Phillips recesses. Courtesy Central Screw Co.

to the point where tension is placed on the bolt. All wedge-type fasteners are re-usable. Their assembly speed is moderate.

B. Spring-Seating Fasteners lock from a lever or spring action within the periphery of the nut or bolt head, as in the Speed Nut and the Place-Bolt, or lock to a component of the nut or the head, as in An-Cor-Lox and Screw Fasteners, Figure 4-35. Spring-seating fasteners are re-usable. Assembly speed is moderate to fast.

C. Spring Stop Nuts have continuous clamping action. They are not free running and thus can be used as stop nuts. See Figures 4-36 and 4-37. Spring stop nuts are re-usable. Speed of assembly is moderate, but not as fast as the wedge-type. The majority of them can be used for moderately rugged applications.

D. Interference Nuts employ a plastic or fiber collar to provide the locking action. These collars are not threaded; they are elastically deformed. Squeezing against the threads, they hold the nut in position. They are not free running and their speed of application is moderate to slow (see Figure 4-38).

E. Blind Screw Fasteners are hardened thread-forming screws made to be installed like sheet metal screws which they replace, as well as blind nuts. Since sheets are held in place by the thread, these fasteners must be designed for the specific application because composite thickness of the material joined will vary. Unlike many other blind fasteners, these are re-usable. Speed of application is equal to or better than that of screw type fasteners. Various types are shown in Figures 4-39, 4-40, 4-41 and 4-42.

F. Quick-Release Fasteners are used for doors and panels where intermittent closing and opening is required, and a positive lock is necessary. Their assembly time is slow, but operation is comparatively fast. Figures 4-43, 4-44 and 4-45 show examples.

4.7 SPECIAL RIVETS

A. Tubular Rivets (See Figures 4-46, 47 and 48). (Sleeve type, sleeve type with one head formed, and solid head type.)

Advantages: Increases bearing area without appreciably increasing weight. Increased ratio of bearing area to effective shear area as compared to solid rivet.

Limitations: Limited to thin sheets, especially for .025-inch or less. Will not resist tensile loads because of nature of head. Shear strength may be limited by buckling characteristics of rivet. For precision work, actual value to be determined by tests. For rough calculations, use shear strength 50 percent of specified strength.

B. Hi-Shear Rivet (See Figure 4-50) (Reg. Trademark)
(Made by Pheoll Mfg. Co., Chicago, Ill., Hi-Shear Rivet Tool Co., and other licensees.)

Advantages: Solid rivet with shear strength in excess of those normally obtainable in standard rivets. Combines drivability of aluminum and the shear strength of cold steel rivets with no loss in holding power.

Limitations: Cannot be driven too tight as excess material of collar is automatically sheared off by special tool.

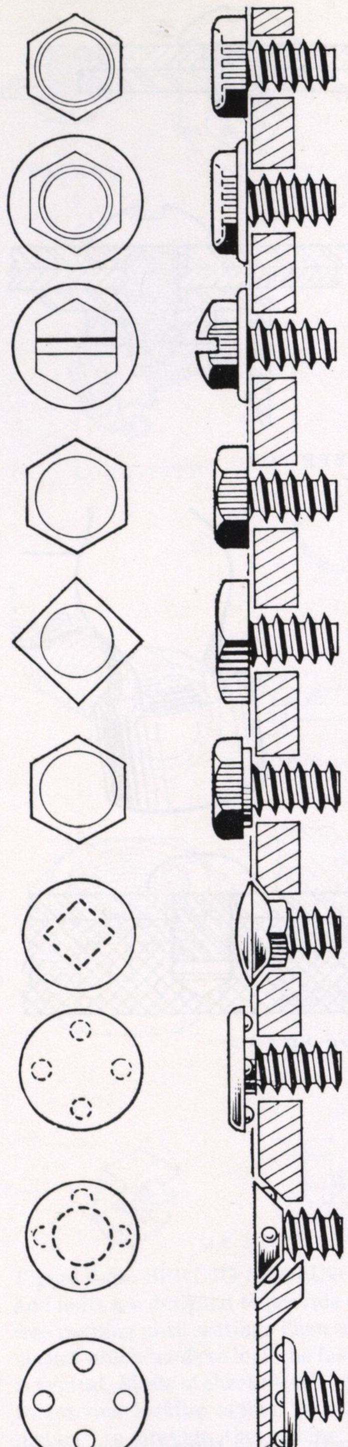
Sizes and Head Types: $\frac{1}{8}$, $\frac{3}{16}$, $\frac{1}{4}$, $\frac{5}{16}$, $\frac{3}{8}$, $\frac{7}{16}$ $\frac{1}{2}$, $\frac{9}{16}$ and $\frac{5}{8}$-inch in 100-degree flat countersunk head, flat binding head or brazier head with various grip lengths.

Materials: Pin: High strength alloy steel or stainless steel, or 7075-T4. Collar: Anodized and waxed 2117-T4.

C. Huck Lockbolt (Huckbolt) (Figure 4-51)

Sizes and Heads: $\frac{3}{16}$, $\frac{1}{4}$, $\frac{5}{16}$ and $\frac{3}{8}$-inch in brazier head, button head and 90-degree countersunk types.

Materials: Pin: Mild steel (cadmium plated for aluminum), or 2024-T4, 6061-T6. Collar: Mild steel (cadmium plated for aluminum) used with mild steel pins. 6061-T6 (with either 2024-T4 or mild steel pin), 6061-T6 (with 6061-T6 pins).



INDENTED HEXAGON: An economical wrench head fastener made to standard hexagon dimensions. With an identifying depression in top surface.

INDENTED HEXAGON WASHER HEAD: Same as above except with washer section at base of head to protect work surfaces against wrench base of head disfigurement.

ACORN HEAD: Domed "hex" locates socket wrenches quickly. Slot permits screwdriver operation. Combines good appearance, fast assembly, protection to work surfaces.

HEXAGON HEAD (TRIMMED): The standard for machine bolts and screws. Square, sharp corners, generous bearing surface for wrench tightening.

SQUARE HEAD (TRIMMED): Accurately dimensioned head is standard for machine bolts; is also available for screws, offers square, sharp corners and generous bearing surface for wrench tightening.

HEXAGON HEAD (FINISHED): Integral washer under head is slightly smaller than diameter across flats, protects the work against disfigurement by head corners during tightening.

SEATING BOLTS: A countersunk square shoulder screw providing neat outside appearance and square shank locking. Finishing washers may be used to further enhance appearance.

HEAD STYLES FOR PROJECTION WELDING SCREWS: Type "U" or underlug is for general application, assembles easily into prelocated holes and fully utilizes head strength. Head designed for efficient electrode contact.

FLAT HEAD styles take full advantage of the self-centering feature of the countersunk portion yet provide a smooth flush outer surface for contacting the electrode.

TYPE "T" or overlug has the welding projections formed on the top of the head. Under surface is designed for good electrode contact. For applications requiring a smooth finished outer surface where head does not show.

Figure 4-31: Standard screw fasteners not ordinarily available in stock. They can be made to any dimensional specifications whenever the quantity involved warrants the tool costs. Courtesy Central Screw Co.

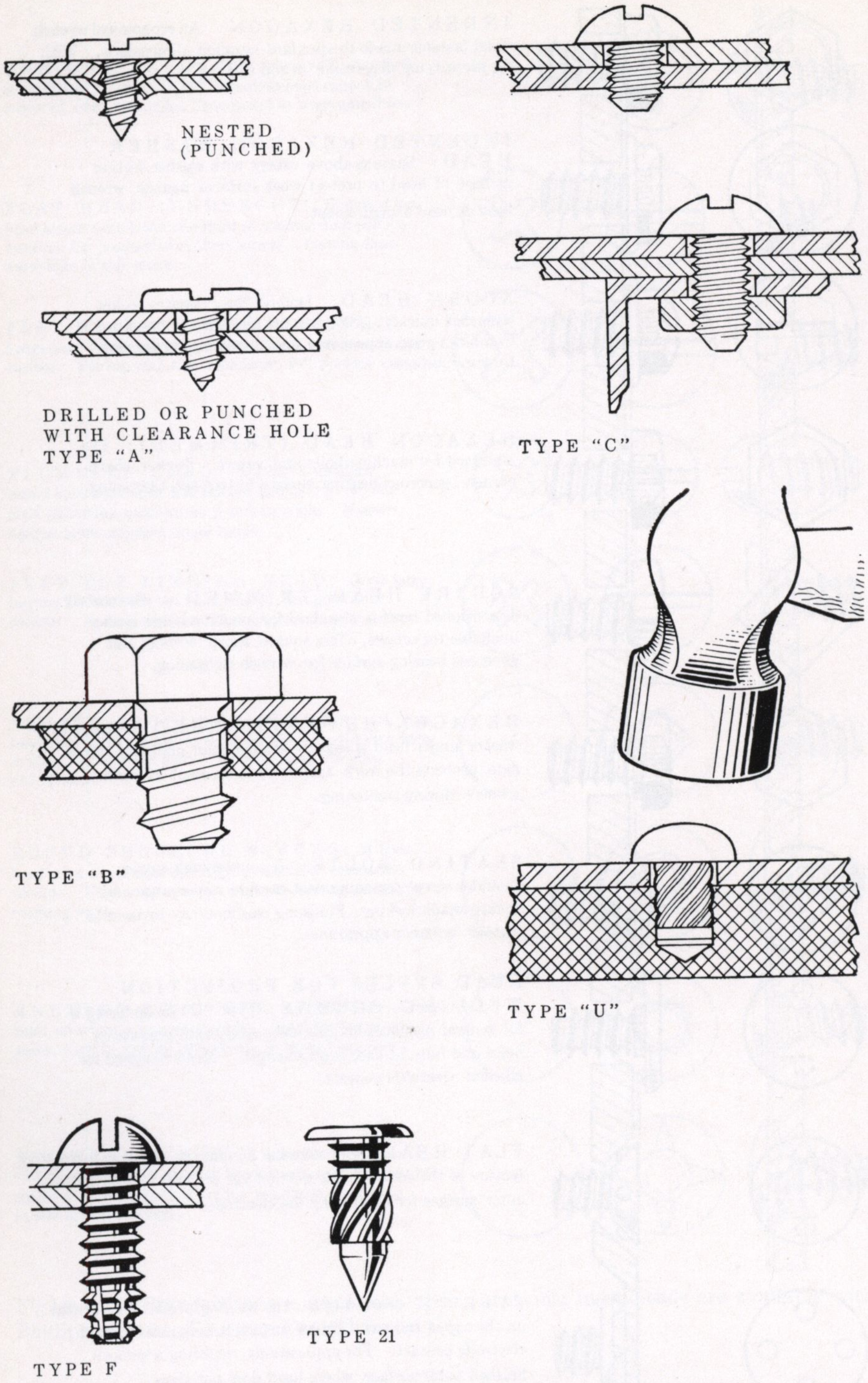
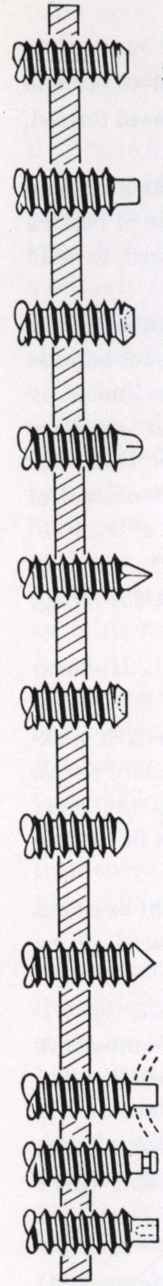


Figure 4-32: Common self-tapping screws: Type A with coarse thread is for joining sheet metal, asbestos, impregnated plywood up to .050-inch in thickness. Type B is for more rugged applications in material up to ½-inch. Type C has standard pitch thread. Type F is for castings. Types U and 21 are driven with a hammer.



DIE POINT: An economical pointing operation at time of heading provides this end chamfer starting with a diameter smaller than the root diameter.

DOG POINT: A straight pointed section with diameter slightly smaller than root diameter to aid starting, insure against stripping fine threads and increase production.

ROLLED POINT: Last thread and a half is slightly cupped by the thread roll-over operation, an efficient method of pointing long studs and screws.

PINCH POINT (Rounded): For aligning several sheets or parts requiring pilot action, end is pinched off in dies producing 60° point, slightly rounded.

NAIL POINT (Pinched): Sharp point with 45° included angle, slightly square surface. For impinging or locking against wood or other soft material.

CUPPED POINT: Depression on end of this point reduces area in contact which increases its holding and locking power under pressure.

ROUND POINT: Dome-like rounded end surface allows point to apply pressure without disfiguring the work. Supplies friction without cutting.

CONE POINT: Precision cut-pointing provides smooth surface, accurate length, sharp point. Can be made with any included angle desired.

CUT POINTS: A variety of tenon ends can be provided in form of straight cut point where the diameter of the tenon end is smaller than root diameter of thread and where a square abutment surface is required. This style point offers excellent bearing surface when assembled into prepared washers or other assemblies requiring free turning pressure surfaces, as in clamps, etc. Cut points can be grooved for special locking rings, cupped for ease in riveting, or machined to special contours for a particular requirement.

Figure 4-33: Most common styles of points.

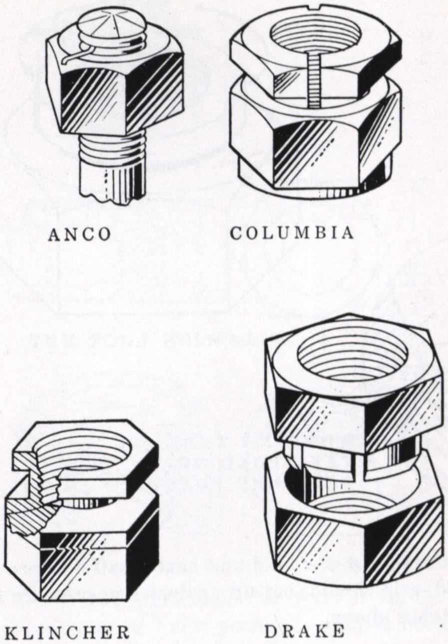


Figure 4-34: WEDGE LOCKING: Four examples of wedge type locking nuts for standard threaded bolts and studs. Anco Nut has wire spring element which engages thread of bolt as shown. Columbia Nut has two elements, the top one being split to wedge against the bolt thread as it is screwed into the tapered lower element. Klincher Nut has tapered upper member which wedges top threads of lower member against bolt. Drake Nut has prongs on upper member which wedge against bolt threads when it is screwed into tapered lower member.

Manufacturers of Wedge Type Fasteners:

Anco	Automatic Nut Co., Inc., Lebanon, Pa.
Columbia	Columbia Nut & Bolt Co., Bridgeport, Conn.
Dardelet	Lamson & Sessions Co., Cleveland, Ohio
Drake	National Screw & Mfg. Co., Cleveland, Ohio
Klincher	Faultless Caster Corp., Evansville, Ind.

Manufacturers of Spring Seating Type Fasteners:

An-Cor-Lox	Laminated Shim Co., Inc., Glenbrook, Conn.
Dynamic	National Screw & Mfg. Co., Cleveland, Ohio
Lock Shock	Costello Lock & Torque Nut Co.
Lock-Tite	Continental Screw Co., New Bedford, Mass.
MF No. 2	MacLean-Fogg Lock Nut Co., Chicago, Ill.
Palnut	The Palnut Co., Irvington, N.J.
Place-Bolt	Place Cap Screw & Bolt Co., Jersey City, N.J.
Sems	Illinois Tool Works, Chicago, Ill.
Speed Nut	Tinnerman Products, Inc., Cleveland, Ohio
Springlock 350	Prestole Corp., Toledo, Ohio
Springnut	Prestole Corp., Toledo, Ohio

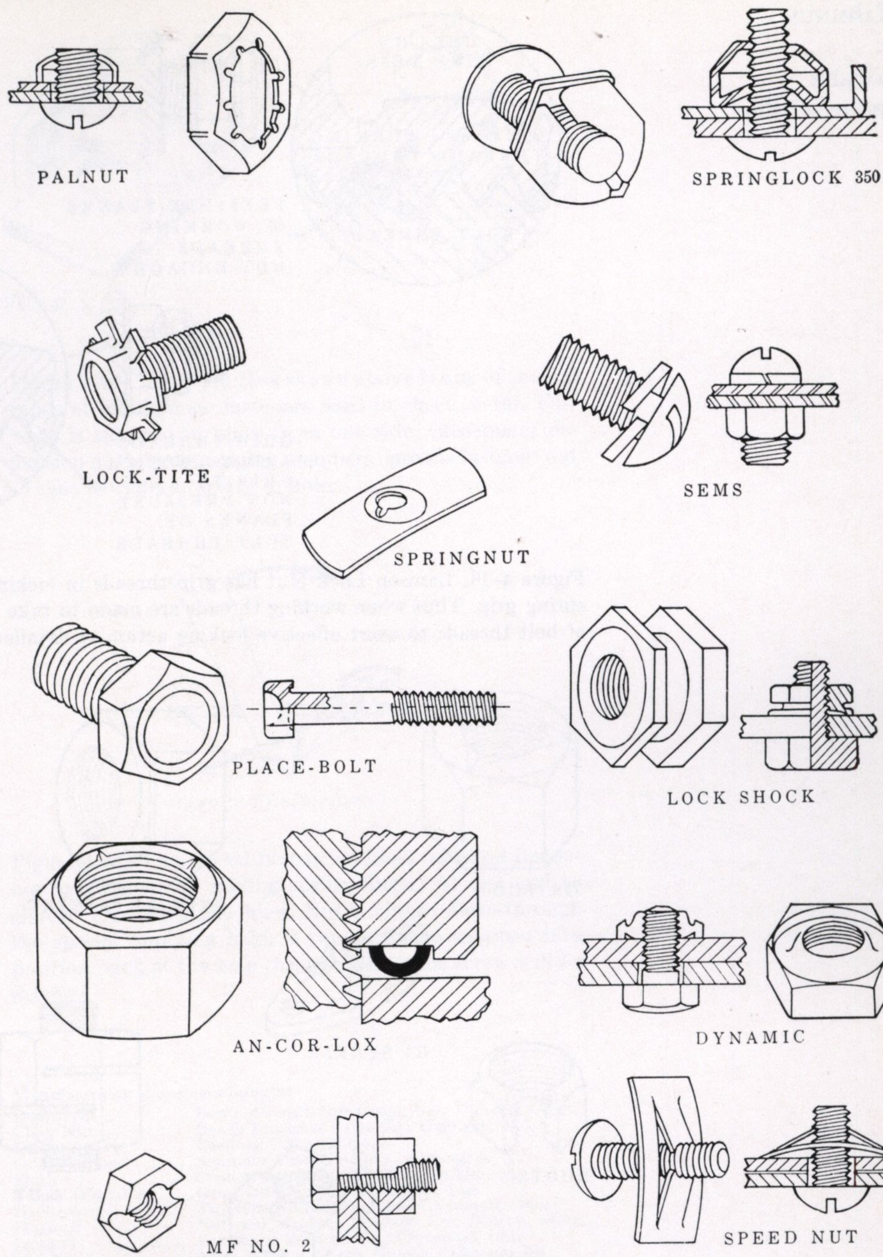


Figure 4-35: SPRING SEATING: All of the above nuts and bolts are designed to provide spring seating. They are free running until seating. Then some sort of spring action occurs which tends to lock the fastener in position. Palnut is typical. Made of sheet metal, body distorts when seated to provide locking action. In the Place-Bolt, the head distorts to provide the locking. In the An-Cor-Lox, a special auxiliary member is compressed. Both body and fingers of Speed Nut are deformed to provide extra strong locking and long spring action. Speed Nut can be pushed over screw until seating commences. Others must be threaded full length of screw section to seat them.

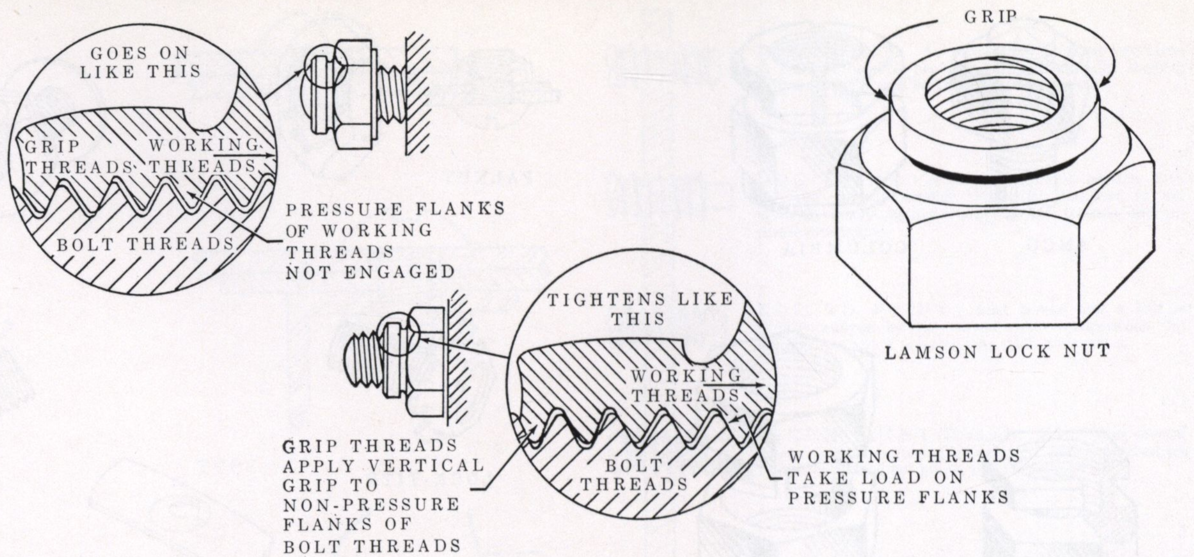


Figure 4-36: Lamson Lock Nut has grip threads in locking collar distorted out-of-round and heat treated to provide a spring grip. Thus when working threads are made to take working load, grip threads set up against non-pressure flanks of bolt threads to exert effective locking action as detailed in the sketches above.

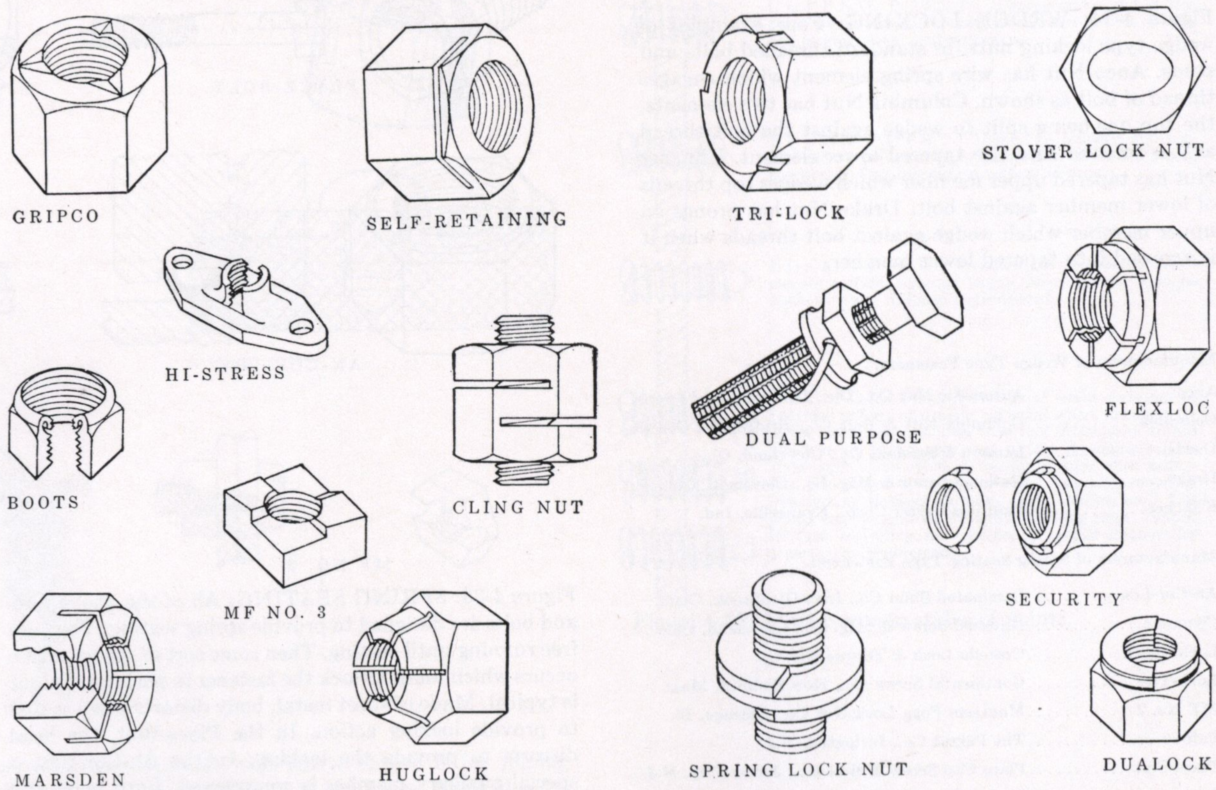


Figure 4-37: SPRING NUTS: All the above lock nuts are distorted before application as against those shown in Figure 4-35 which are not distorted until seated. Yet they depend upon distortion of the threaded element for their locking action, with the exception of the Dual-Purpose Nut which has a wire spring engaging slots in the screw. These nuts are not free running as are the spring seating types shown in Figure 4-35.

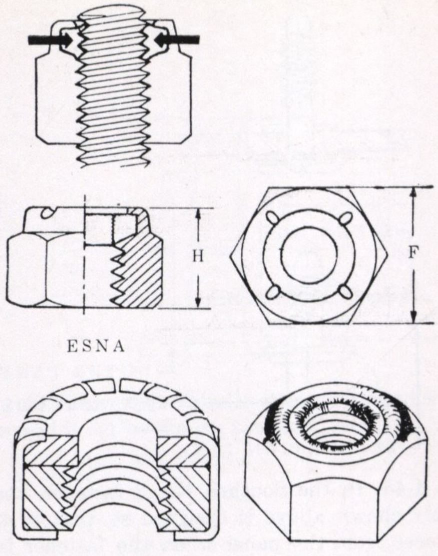


Figure 4-38: INTERFERENCE NUTS: In this type lock nut, a collar of fiber, plastic or similar material is incorporated into the nut. Collar is smaller than screw so it must be distorted when nut is threaded onto screw. Friction between collar and screw threads provides good locking action shown at top left.

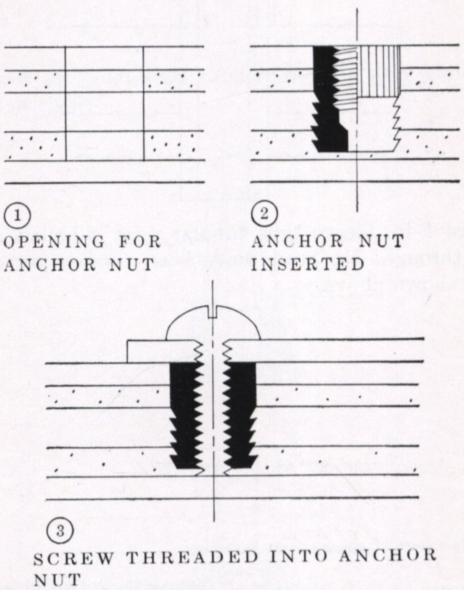


Figure 4-39: Southco Anchor Nut is not only a blind screw fastener but also offers a certain amount of locking action. As the screw is threaded into it, the lower tapered prong sections are forced to expand sidewise into the work. In turn they tend to lock the screw by continued pressure they exert on the bolt threads. Also since the screw must cut the lower threads, these are tight, in turn helping to lock the screw.

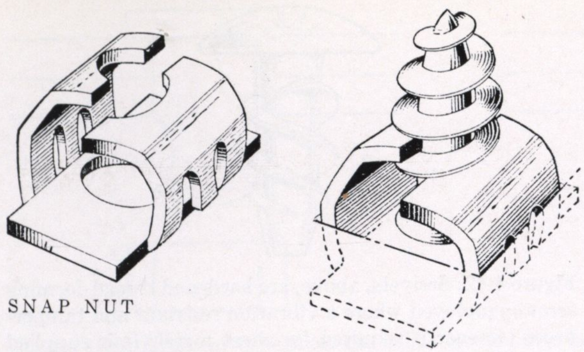


Figure 4-40: The Snap Nut shown above is one of several types of blind screw fasteners used in sheet metal. Fastener is snapped in place from one side, subsequent expansion of thread-engaging members spreads fastener out so that it wedges tightly in hole.

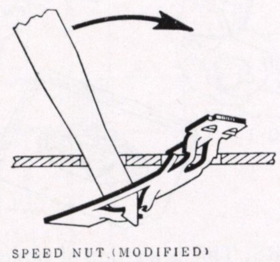


Figure 4-41: This Speed Nut is modified for blind fastening application by adding spring fingers at one end as shown. Then when the Speed Nut is slipped down through the special applying hole, it can easily be snapped into position back of the hole through which the screw will be driven.

Manufacturers of spring stopnuts:

Boots Nut	Boots Aircraft Nut Corp., New Canaan, Conn.
Cling Nut	Beach Precision Parts Co., Harrison, N.J.
Dualock	Dualock Products Co.
Dual Purpose	Simmons Fastener Corp., Albany, N. Y.
Flexloc	Standard Pressed Steel Co., Jenkintown, Pa.
Gripco	Grip Nut Co., South Whitely, Ind.
Hi-Stress	Tinnerman Products, Inc., Cleveland, Ohio
Huglock	National Machine Products Co., Detroit, Mich.
Lamson	Lamson & Sessions Co., Cleveland, Ohio
MF No. 3	MacLean-Fogg Lock Nut Co., Chicago, Ill.
Security	Security Locknut Corp., Chicago 5, Ill.
Spring Locknut	George K. Garrett, Inc., Philadelphia, Pa.
Stover Locknut	Stover Locknut & Machinery Corp., Easton, Pa.
Self-Retaining	Columbia Nut & Bolt Co., Bridgeport, Conn.
Tri-Lock	Boots Aircraft Nut Corp., New Canaan, Conn.
Marsden	American Marsden Co., Jersey City, N.J.

Manufacturers of interference stopnuts:

Esna	Elastic Stop Nut Corp. of America, Union, N.J.
Nylok	Russel Burdsall & Ward Bolt & Nut Co., Port Chester, N.Y.
Pem	Penn Engineering & Mfg. Co., Doylestown, Pa.

Manufacturers of blind screw fasteners:

Scrivet	National Screw & Mfg. Co., Cleveland, Ohio
Snap Nut	Prestole Corp., Toledo, Ohio
Southco Anchor Nut	South Chester Corp., Philadelphia, Pa.
Speed Clip	Tinnerman Products, Inc., Cleveland, Ohio
Speed Nut (Modified)	Tinnerman Products, Inc., Cleveland, Ohio

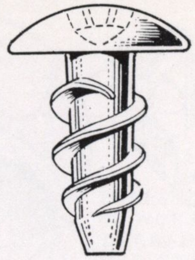


Figure 4-42: Scrivets, above, are hardened thread-forming screws employed where a vibration resistant and tamper-proof fastener is required for sheet metal. It is supplied with a Phillips recessed head.

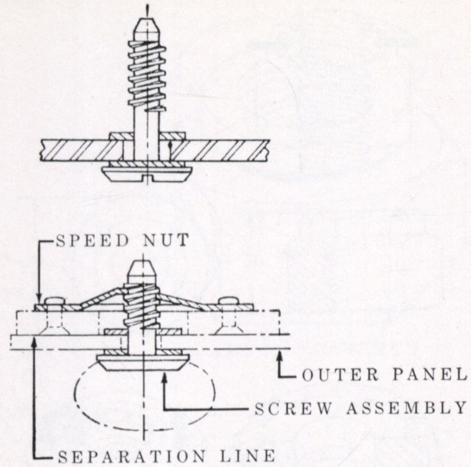


Figure 4-45: In the Southco No. 2 fastener, the screw assembly shown above is designed so that it does not come loose from the panel when the fastener is disengaged. Note a Speed Nut is riveted to the back side of the second part to be joined, engaging and locking the screw against vibration.

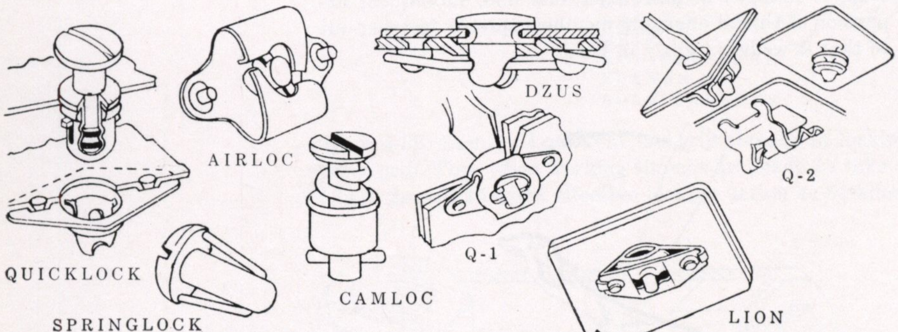


Figure 4-43: QUICK-RELEASE FASTENERS: This is a group of typical quick-release fasteners for use in attaching inspection doors and similar applications. Turning one element with a screw-driver produces a cam-like engagement with another element in most of these systems. Turning in opposite direction subsequently disengages the members quickly with only a partial turn of the screw-driver. This contrasts with regular screw fasteners which must be rotated many complete turns to engage or disengage the members.

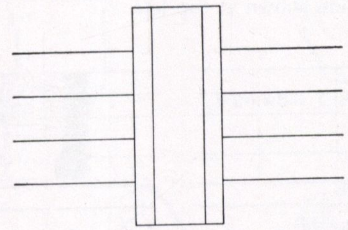


Figure 4-46: Sleeve type tubular rivet is hollow all the way through. No heads have been formed yet on the rivet shown above.

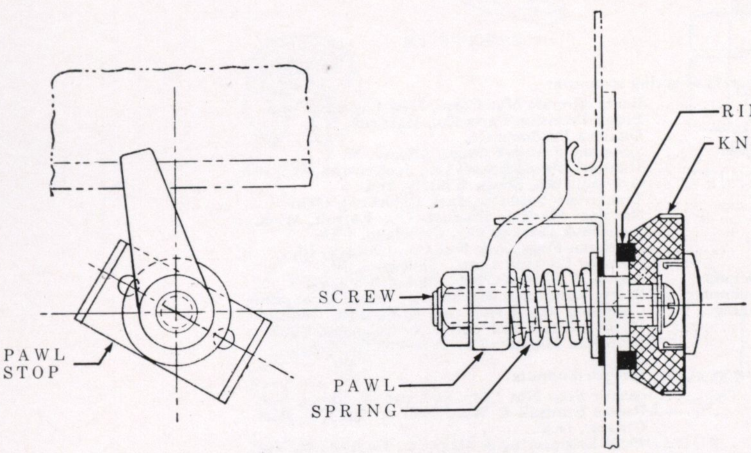


Figure 4-44: Here is shown another type of quick-release fastening system, the Southco No. 11 Adjustable Pawl Fastener. Note coiled spring to retain pawl in any position and the pawl stop which positions pawl at desired point of engagement. Pawl engages bead rolled on edge of panel or door opening.

Manufacturers of quick-release fasteners:

Airloc.................United-Carr Fastener Corp., Cambridge, Mass.

Camloc...............Camloc Fastener Corp., New York 17, N.Y.

Dzus.................Dzus Fastener Co., Inc., Babylon, N.Y.

Lion..................Lion Fastener, Inc., Honeoye Falls, N.Y.

Q-1 & -2.............Shakeproof, Inc., Chicago, Ill.

Quicklock & Springlock.Simmons Fastener Corp., Albany, N.Y.

Southco No. 2 & No. 11..South Chester Corp., Philadelphia, Pa.

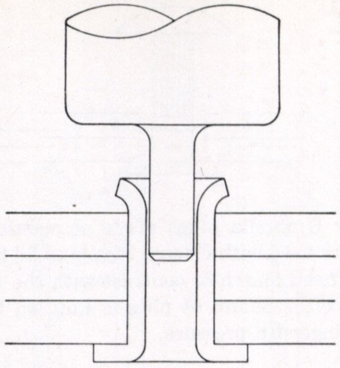


Figure 4-47: Sleeve type tubular rivet purchased with one head formed is set by simple tooling shown here.

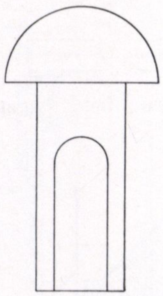


Figure 4-48: Solid-head tubular rivet is only hollow in shank of rivet.

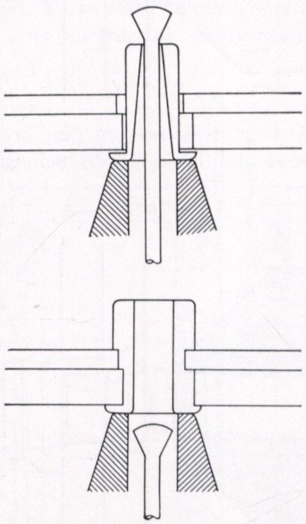


Figure 4-49: Chobert Rivet. A mandrel is used to expand the shank, leaving essentially a tubular rivet. It can be plugged if additional strength or water tightness is required. Mandrel is reusable. Riveting can be done by hand or machine.

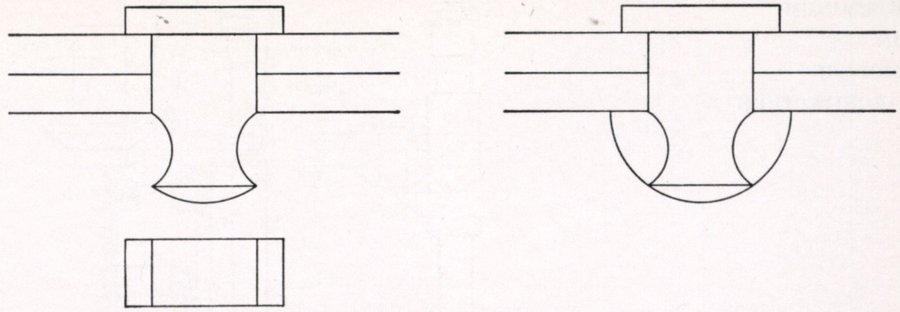
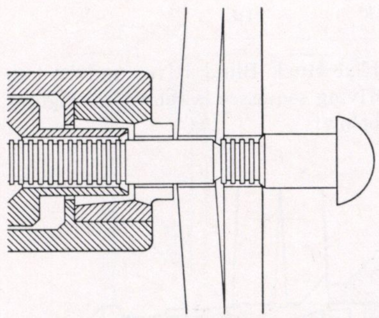
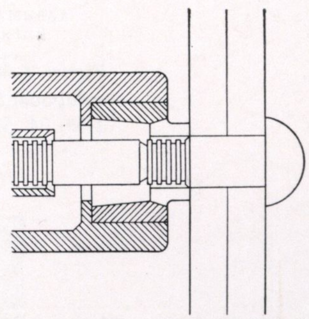


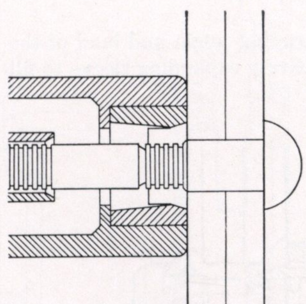
Figure 4-50: Hi-Shear type rivet has collar formed into head which locks around shaped shank of cadmium-plated steel to provide a solid rivet stronger than usual rivets.



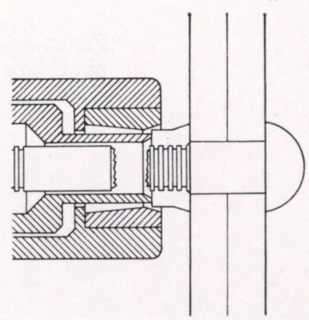
1. PIN HAS BEEN INSERTED FROM ONE SIDE, COLLAR PLACED FROM OTHER SIDE. GUN JAWS ENGAGE PULL GROOVES ON PIN.



2. INITIAL PULL FROM GUN CLAMPS WORK PIECES TOGETHER TIGHTLY, FILLS HOLE BY PRESS FIT AT ENLARGED SHANK.



3. INCREASED PULL FORCES GUN ANVIL DOWN OVER LOCKING COLLAR, SWAGING IT INTO LOCK GROOVES OF PIN.



4. FURTHER PULL BREAKS OFF PIN TO COMPLETE SEQUENCE OF OPERATIONS.

Figure 4-51: Huck Lockbolt and how it is applied.

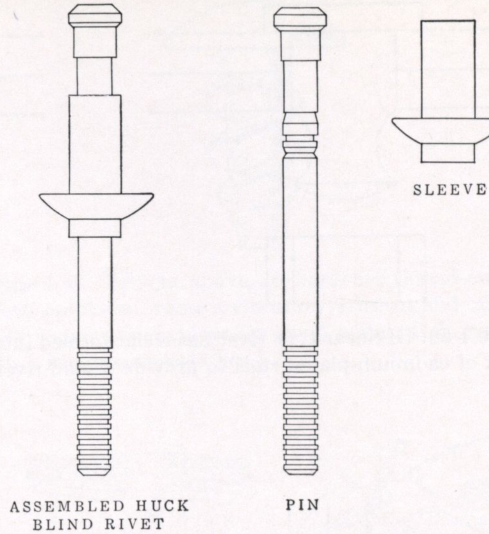


Figure 4-52: Assembled Huck Blind Rivet and its two component parts. Driving sequence is shown in Figures 4-53, 54, 56 and 57 below:

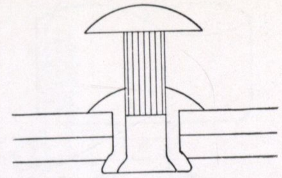


Figure 4-55: Umbrella plugs made of plastic, copper or aluminum are used with Cherry Rivets to fill the shank or to have the head match or contrast with the color of the material surface. Shank of plug is knurled for easy insertion by finger-tip pressure.

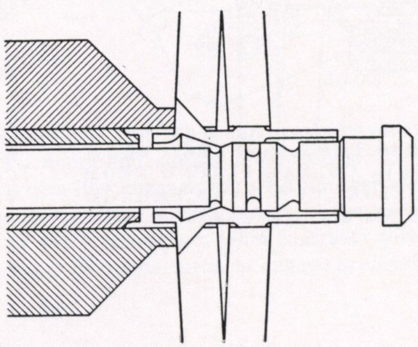


Figure 4-53: Gun pulls extruding angle and land of the pin through the sleeve, positively expanding sleeve to fill rivet hole.

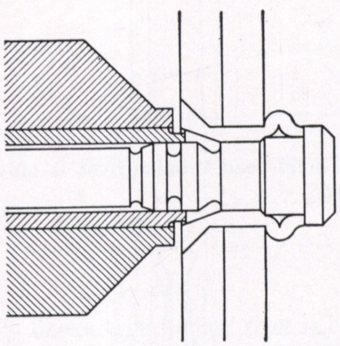


Figure 4-56: Driver inside nose of gun breaks off outer collar from sleeve and forces it into locking groove.

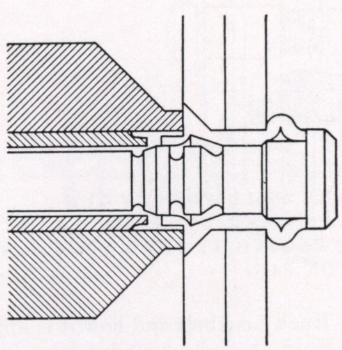


Figure 4-54: Sleeve is squeezed between head of pin and nose of gun upsetting sleeve end to form driven head on blind or backside of work.

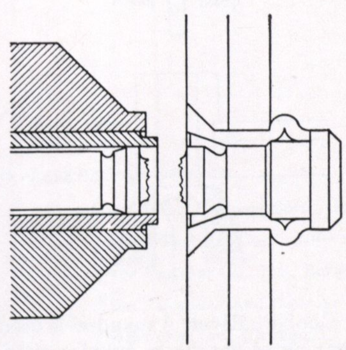


Figure 4-57: Pin is broken off in tension at breakneck groove as gun continues to move pin.

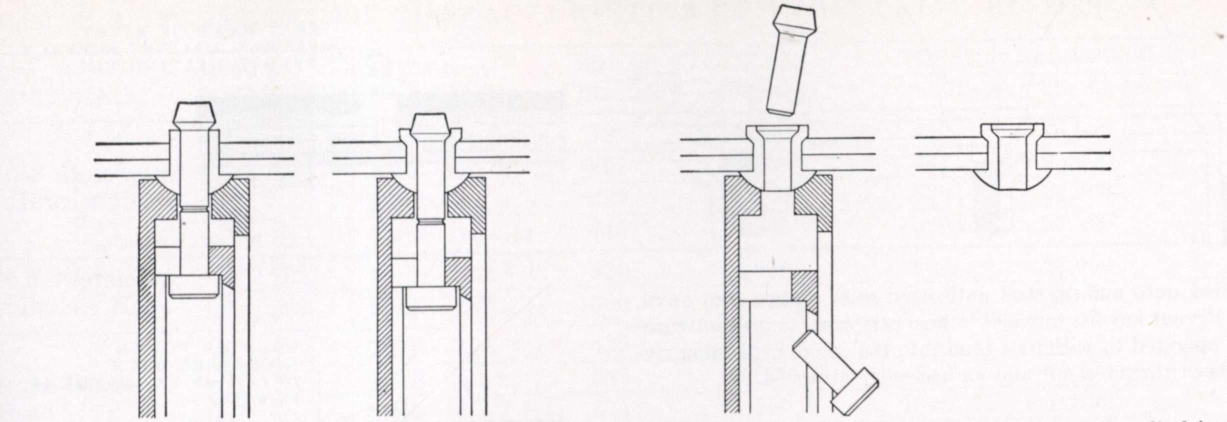


Figure 4-58: Hollow member and stem of the regular type Cherry Blind Rivet are inserted in hole. Stem is pulled, cylindrical upsetting head expands rivet tail to form tulip head. Continuing pull fractures stem which drops out of the head and the tail of rivet as shown.

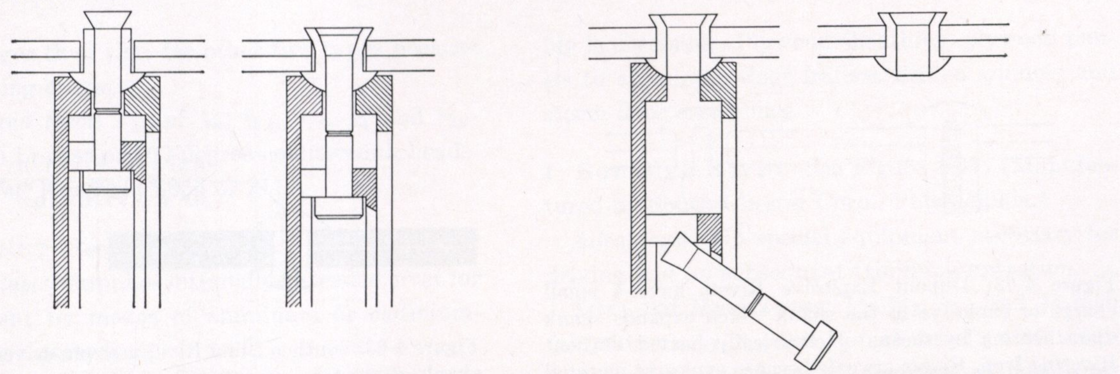


Figure 4-59: Pull-through type Cherry Blind Rivet assembly is inserted in hole. Gun pulls conical head of stem into rivet, upsetting rivet tail to form tulip head. Continuing pull draws conical head entirely through rivet, thereby expanding shank. Stem falls out through slot in head of gun. This system avoids any broken stem inside the assembly.

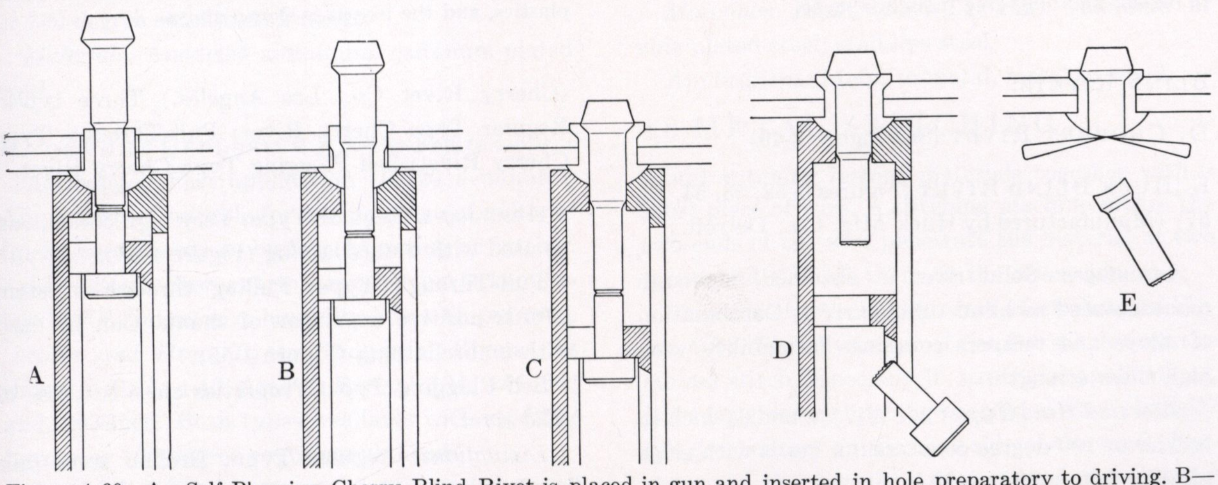


Figure 4-60: A—Self-Plugging Cherry Blind Rivet is placed in gun and inserted in hole preparatory to driving. B—Pull from gun is drawing enlarged portion of stem into shank of rivet, expanding it to fill the hole. C—Continued Pull has expanded all of rivet shank, conical tip of stem has upset rivet tail to form head. D—Gun exerts increased pull to break stem at notch. Gun end of stem now falls out; other end remains in rivet. E—The job is finished by cutting off the projecting stem flush with the head of the rivet as shown here.

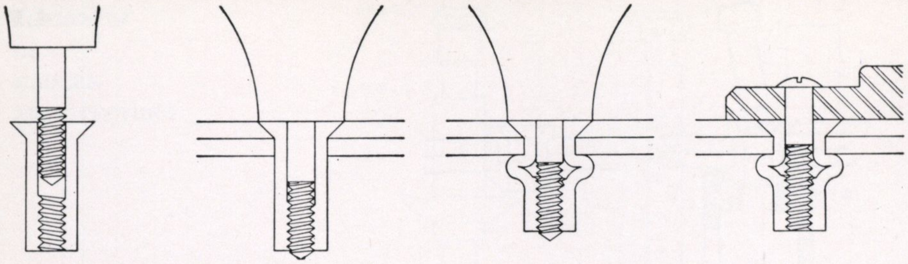


Figure 4-61: Rivnut is threaded onto pull-up stud until head rests against tool anvil. Rivnut is inserted into hole. Rivnut key fits into slot in hole periphery to prevent turning after attachment. Tool is operated to withdraw stud into tool nose, expanding rivnut as shown. Tool stud has been threaded out and an accessory attached.

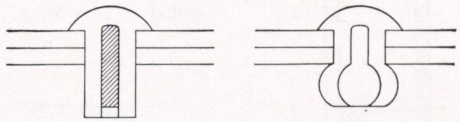


Figure 4-62: Dupont Explosive Rivets have a small charge of explosive in the shank which expands shank upon heating by means of electrically heated DuPont Riveting Iron. Rivets are safe because explosive material is precisely controlled to not explode until exactly 120° temperature is reached. This guards against premature explosion during storage or handling. Rivets are available in regular and blast-free (noiseless) type.

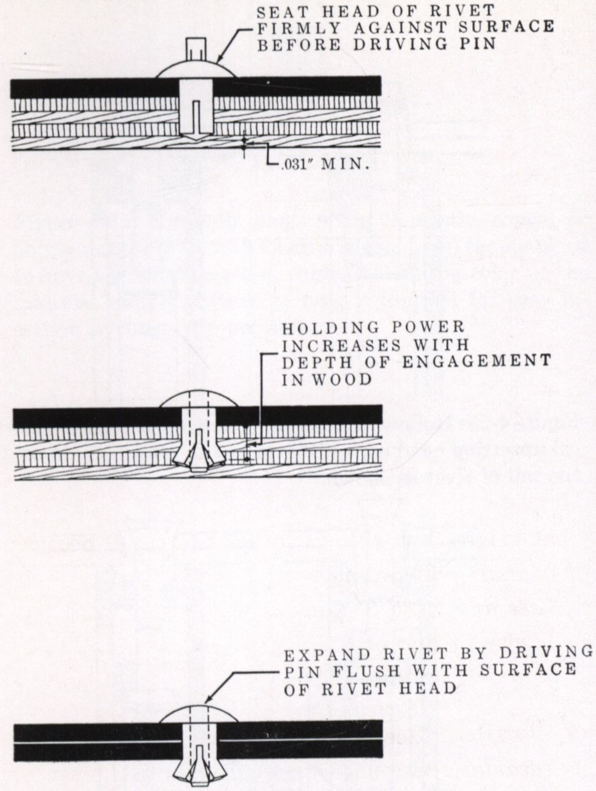


Figure 4-63: Southco Blind Rivet uses pin driven through shank of rivet to expand tail of rivet by wedge action against tapered members. Southco Blind Rivet can be used for joining aluminum to aluminum as shown at bottom and also is suitable for joining aluminum to wood, plastics, and the like as is shown above.

BLIND RIVETS:

D. CHOBERT RIVET (See Figure 4-49)

E. HUCK BLIND RIVET (Figures 4-52, 53, 54, 56, 57) (Manufactured by Huck Mfg. Co., Detroit.)

Advantages: Solid rivet is obtained, although manufactured as blind tubular rivet. Combination of alloys and tempers combines formability with high shear strength.

Sizes and Head Types: $\frac{1}{8}$, $\frac{5}{32}$, $\frac{3}{16}$ and $\frac{1}{4}$-inch in brazier or 100-degree countersunk heads with grips ranging from .020 to .420-inch.

Materials: Pin: 2024-T36. Sleeve: 5056-H14.

F. CHERRY RIVET (Figures 4-55, 58, 59, 60) (Cherry Rivet Co., Los Angeles.) Three types: Regular Type Cherry Rivet; Pull-Through Type Cherry Rivet; Self-Plugging Type Cherry Rivet.

Advantages: Regular Type: Very high clinch, can be used with umbrella plug (Figure 4-55).

Pull-Through Type: Pulling through of stem affords positive expansion of shank. Can be used with umbrella plug (Figure 4-55).

Self-Plugging Type: Properties close to those of solid rivet.

Limitations: Regular Type: Broken stem falls into assembly. Shank is not expanded.

Pull-Through Type: Clinch not as high as with regular type, but comparable to a solid rivet.

Self-Plugging Type: Time of application some-

TABLE 4-19: STRENGTH CHARACTERISTICS OF INDUSTRIAL RIVETS

RIVET MATERIAL	RIVET DIAMETER	RIVET NUMBER	SHEAR STRENGTH Lbs/Rivet	SHEAR STRENGTH Lbs/Sq In.*	TENSILE STRENGTH Lbs/Rivet	TENSILE STRENGTH Lbs/Sq In.*
5052 Aluminum Brazier Head	1/8″	52SB—1/8 x 3/16	187	15,200	290	23,600
	5/32″	52SB—5/32 x 3/16	291	15,200	441	23,000
	3/16″	52SB—3/16 x 3/16	420	15,200	630	22,900
	1/4″	52SB—1/4 x 1/4	743	15,200	1020	23,000
5056 Aluminum Brazier Head	3/16″ (.202″)	56SB—202 x 1/8	800	25,000	900	28,000
	1/4″ (.263″)	56SB—263 x 1/4	1360	25,000	1540	28,000
Brass Brazier Head	1/8″	BRB—1/8 x 3/16	425	34,600	603	49,200
	5/32″	BRB—5/32 x 3/16	641	33,600	882	46,100
	3/16″	BRB—3/16 x 3/16	874	31,900	1345	51,700
	1/4″	BRB—1/4 x 3/8	1350	28,600	2200	45,000

* Calculated on actual shank diameters of rivets. Area of cavity not subtracted.

what longer than that for other two types because of trimming operation.

Sizes and Head Types: 1/8, 5/32, 3/16, 1/4 and 9/32-inch with brazier or 100-degree countersunk heads.

Material: Anodized 5056 or 2117.

G. Rivnut (See Figure 4-61)

Advantages: Supplies internally threaded rivet for attachment by means of aluminum or cadmium-plated steel screws.

Sizes and Head Types: .157, .189, .221, .251, .332 and .413-inch in thread sizes 4–40, 6–32, 8–32, 10–32, 1/4–20, 5/16–18, respectively, with flat heads or 100-degree countersunk heads.

Materials: Anodized aluminum, cadmium-plated steel.

H. duPont Explosive Rivet (Figure 4-62)

Advantages: Fast application (15–20 a minute). Any size rivet suitable for a wide range of material thicknesses. Needs no buffing, trimming or cutting.

Limitations: Storage temperature must be kept below 120°F and relative humidity below 85 per cent.

Sizes and Head Types: Industrial Rivets: As shown in Table 4-19. Aircraft Rivets: .134, .171 .202 and .263-inch. Both types available with modified brazier or 100-degree countersunk head.

Material: 5052 aluminum, brass, nickel-plated brass, nickel, 5056-F aluminum, 2017-T4 and 5056-F alodized aluminum.

Applications: Generally, where one side of assembly is accessible. Plywood sheathing, plywood panels to aluminum door frames. Screen window and storm door assemblies.

I. Southco Rivet (See Figure 4-63) (Manufactured by South Chester Corp., Philadelphia.)

Advantages: No special equipment necessary for driving and no subsequent trimming operation.

Sizes and Head Types: 1/8, 5/32, 3/16 and 1/4-inch (aluminum), 1/8, 3/16 and 1/4-inch (steel); with modified brazier or 100-degree countersunk heads for aluminum, and modified brazier head or 78-degree countersunk head for steel.

Materials: Rivet: 2117-T4. Pin: Cadmium or zinc plated steel; stainless steel.

Applications: Metal to metal, metal to wood.

4.8 METAL STITCHING

Metal stitching fastens materials together with a short piece of wire. A stitching machine makes the two ends of the wire penetrate the material at two points and clinches them on the other side.

There are basically two types of stitches, see Figure 4-64. The advantage of the flat stitch over the curved stitch, especially in structural applications, is its far greater clinching pressure with a virtually full line contact on the back side of the work. Furthermore, the flat stitch does not cut the material as it leaves the holes as does the curved stitch. The curved stitch is not recommended where strength and resistance to vibration are required. It provides

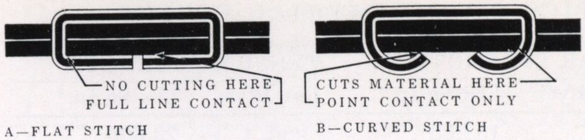


Figure 4-64: Flat stitch (A) and curved stitch (B).

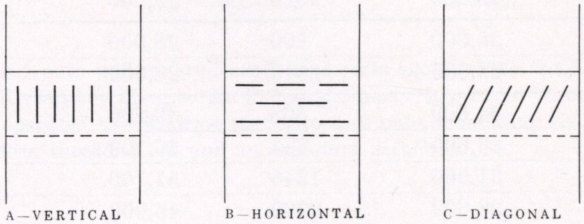


Figure 4-65: (A) vertical, (B) horizontal and (C) diagonal methods of stitching.

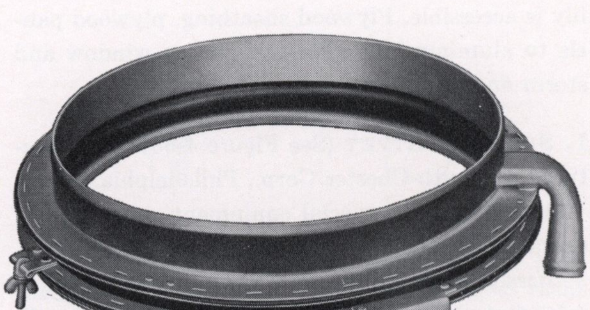


Figure 4-66: Wire stitching provides excellent mechanical joint between metal and rubber, fabrics or plastics. Here a rubber element is stitched between two flanges making an air-tight assembly, yet prevents transmission of vibrations through large air duct. Similar applications in heating, ventilating, air-conditioning systems permit quick fastening of nonmetallics to aluminum to isolate various sections of ducts and equipment.

only point contacts in contrast to the line contacts of the flat stitch.

Compared to spot welding, stitching is twice as fast and does not require any precleaning. Its speed of application is ten times as fast as riveting. The work to be stitched need not be clamped, drilled or punched. Considering fatigue, stitched seams are at least as good as riveted joints.

Three different ways of laying out stitches on a lap seam are shown in Figure 4-65. Method (A) is preferred from a production standpoint, but is weakest because stitches are in direction of shear. Method (B) is stronger, but not so strong as method (C) which should be applied whenever maximum shearing strength is required.

Conditions peculiar to the job, such as the hardness of the material to be joined, size of the machine, size and hardness of the wire employed, will govern the thickness of the material that can be joined. Although dead soft material having a composite thickness of ¾-inch has been joined, metal stitching is usually confined to thinner materials. As an example, the following limits, although not binding, have been established for 2024 sheets. As heavier equipment is developed, these limits will be increased.

Alloy and Temper	Total Composite Thickness (In.)	Maximum Sheet Thickness (In.)
2024–0	.160	.084
2024–T3	.080	.051
2024–T36	.070	.051

A wire which has proved satisfactory for aluminum stitching is a 0.0475-inch AISI-1086 steel wire with a 0.0015-inch thick zinc coating to prevent electrolytic corrosion (see Section 2.4); this wire has an approximate tensile strength of 290,000–330,000 psi.

Wire stitching is also well suited for joining aluminum to plastics, rubber, cork, asbestos and similar material (see Figure 4-66).

4.9 MECHANICALLY FORMED JOINTS

These are connections obtained by forming or cutting the parts to be joined in such manner that they interlock. Mechanically formed joints for aluminum sheet do not differ basically from such joints in other metals. Where high strength is of primary importance, other joining methods will usually be preferred. But the building industry offers many applications, such as roof work, ducts, gutters, downspouts, railings, where mechanically formed joints are quite satisfactory. Where necessary, they can be made watertight by means of aluminum cold solder.

Figure 4-69 shows joints readily disassembled. The tube-rod joint in Figure 4-74 is not intended to be disassembled. Other mechanically formed joints appear in Figures 4-70 and 4-73. Mechanically

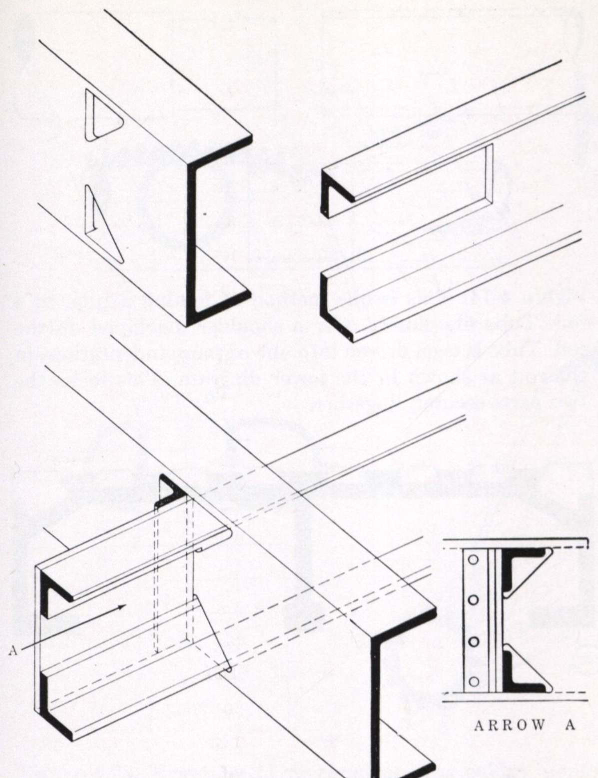


Figure 4-67: Intersecting extrusions can be joined by routing holes in one shape, permitting portions of the second shape to run through. Joint is then reinforced by backup plate and angle.

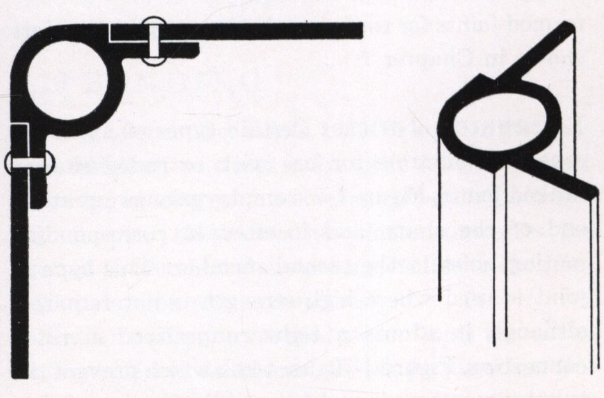


Figure 4-68: Example of hollow extruded shape used as corner post.

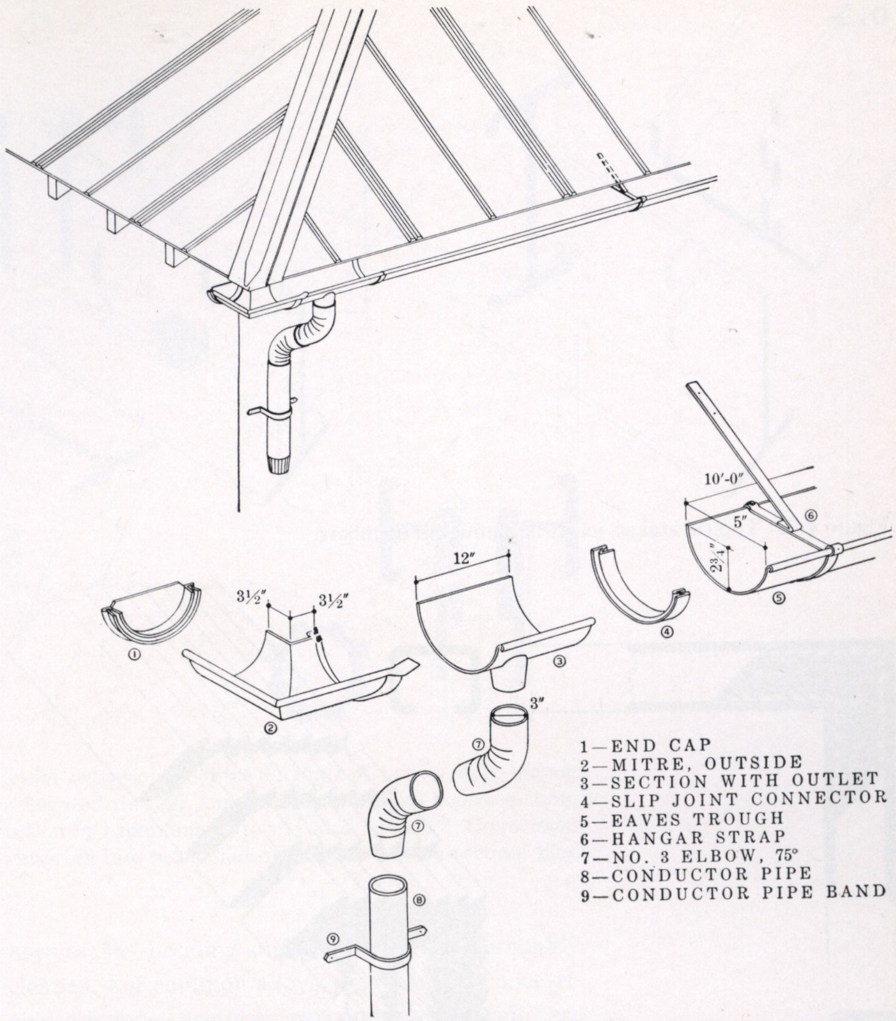


Figure 4-69: Aluminum rain-carrying equipment shown above employs mechanical fastening system based on the slip-joint.

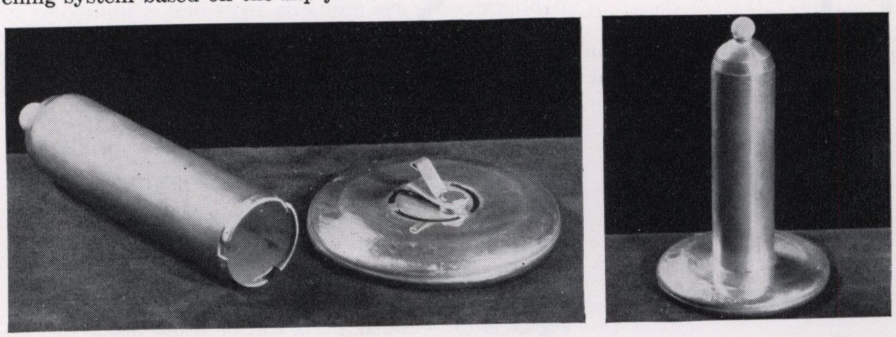


Figure 4-70: This night light affords example of the "bayonet" type mechanical fastening system. Three bayonet members stamped on end of tube engage in circular openings in bottom plate. When inserted and turned, the angle of bayonet slot in tube ends draws assembly up tight, yet can easily be disassembled and reassembled for insertion of new batteries when required. This nifty night light has a plunger switch in the bottom which turns on light only when lifted from table.

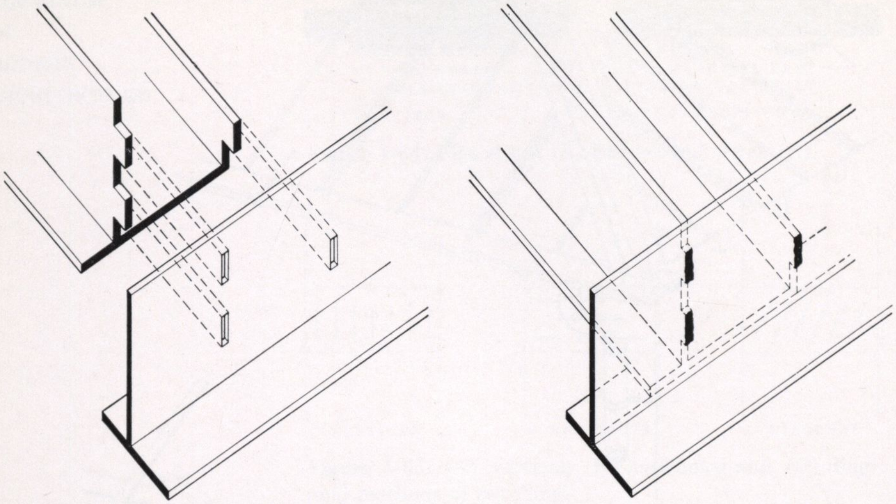


Figure 4-71: Typical staked joints in aluminum members.

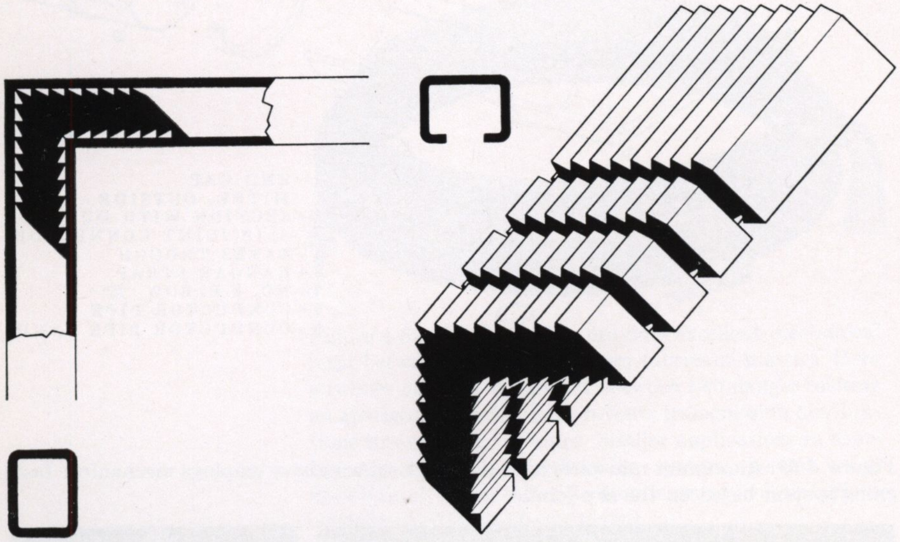


Figure 4-72: Extruded aluminum window-frame sections can be joined by staking them to serrated corner section, cut from aluminum extrusion of staked joint as shown.

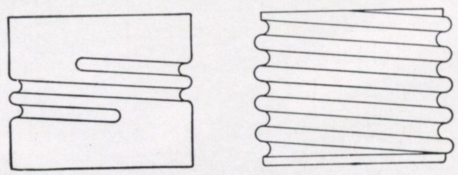


Figure 4-73: Tubular parts can be fitted inside one another and joined mechanically by means of threads rolled on each of the two members as shown. Engaging the threads then joins the parts. Axial position in relation to each other is adjustable, but they can be locked in place by upsetting both parts with a punch or by crimping to prevent rotation and disengagement.

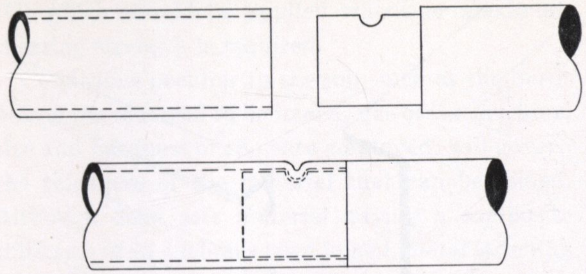


Figure 4-74: This is one method of joining a tube to a rod. Tube fits closely over a shoulder machined on the rod. Tube is then driven into one or more indentations in the rod as shown in the lower diagram. This locks the two parts securely together.

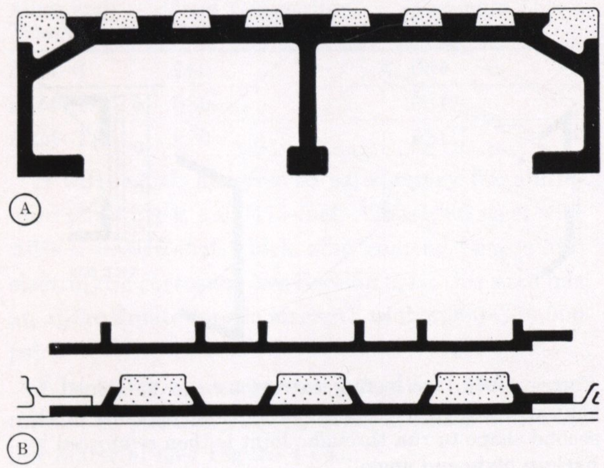


Figure 4-75: When increased resistance to abrasion is desired, aluminum extrusions can be protected by strips or shapes of rubber, plastic, steel or brass. Section A shows safety steps with slip-preventing abrasion-resistant inserts. Ribs in Section B are extruded straight, then bent over to lock rubber strips in place.

formed joints for roofing and siding applications are shown in Chapter 7.

EXTRUSION JOINTS: Certain types of joints are especially suitable for use with extruded shapes. Staked joints, Figure 4-71, employ prongs cut at the end of the shape and inserted in corresponding mating holes in the second member. This type of joint is used where high strength is not required, although it affords a tight connection. Serrated connectors, Figure 4-72, use teeth which prevent the tubular members joined from sliding back and thus assure a tight fit. Intersection joints, Figure 4-67,

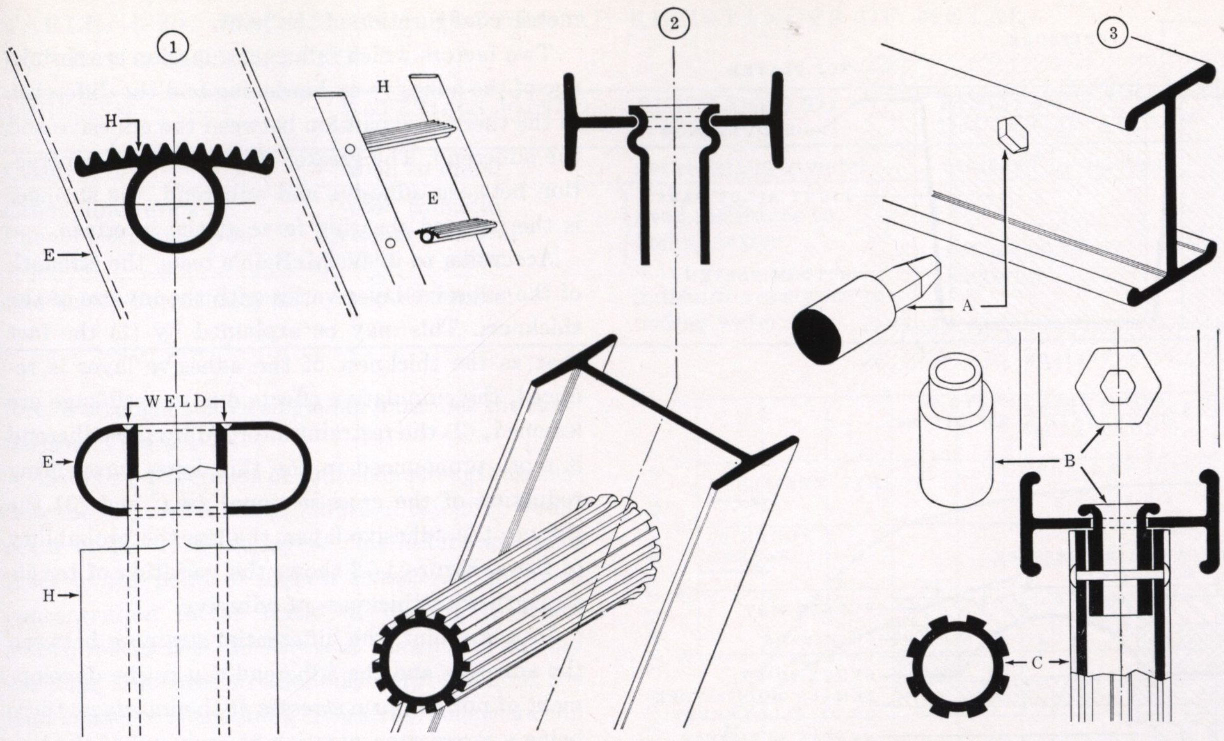


Figure 4-76: Examples of mechanical interlocking joints in tubular extrusions. Sketch 1; Ends of hollow step, section H, are trimmed to leave only the tubular section, which is then inserted through and welded to vertical hollow section, E. Sketch 2; Tubular ladder rungs are joined to solid upright section by expanding to form beads. Sketch 3; Connection is made by shouldered ring, B, which is riveted to extrusion, C, inserted into hexagonal opening in I-beam section, then expanded and upset with steel tool, A.

permit forces to be transmitted with the least possible degree of interruption. Joined parts may be riveted. Solid aluminum extrusions can be joined to tubular members in various ways, as in Figures 4-68 and 4-76. Protection of edges and surfaces against wear is accomplished with inserts as shown in Figure 4-75.

4.10 BONDING

Joining by means of rivets, bolts or similar mechanical fasteners provides only local junctures; butt welding, brazing and soldering generally join the faying area. However, these latter processes are limited to metals and are not applicable to the joining of aluminum to non-metals.

Resin bonding, a method which joins the entire faying surface, utilizes adhesives for bonding aluminum to aluminum, aluminum to other metals, or aluminum to non-metals. Prior to applying the adhesives, the bonding surfaces should be thoroughly cleaned. For common alloys, degreasers such as trichlorethylene, acetone, carbon tetrachloride are adequate. For strong alloys, mild alkaline cleaners or phosphoric acid type cleaners are recommended.

The adhesives, except for those of the thermoplastic type, must be applied prior to the assembly of the joint. Unless available as a tape or thin film, the adhesive will be in solution form and may be applied by brushing, spraying, roller coating or dipping. Adhesives of the thermoplastic type may be applied by means of gravity or capillary action, after the joint has been assembled. For effective bonding, the application of heat and pressure must conform to the manufacturers' specifications.

The joint design must be stable enough to carry the applied bonding pressure in direct compression, otherwise the design must be such as to allow for the insertion of packing blocks to relieve part of the

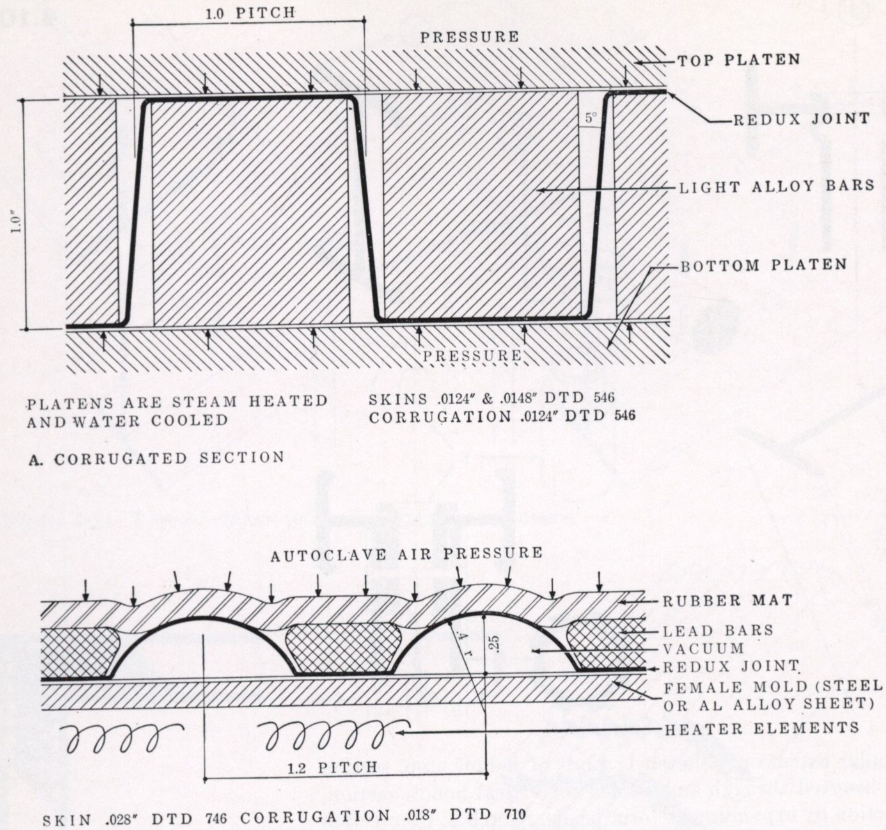


Figure 4-77: The application of pressure to Redux joints.

load. Figure 4-77 illustrates this latter condition.

There is no universal adhesive that can be employed for all resin bonds. The nature of the materials joined and the ultimate conditions of service determine the type of adhesive to be used. Proprietary adhesives developed especially for bonding metals include Redux (Resinous Products & Chemical Co.), Cycleweld (Cycleweld Div. of Chrysler Corp.), Reanite (U. S. Stoneware Co.), Metalbond (Consolidated Vultee Aircraft Corp.), Araldite (Ciba Corp.), and others by the Goodyear Tire & Rubber Co., U. S. Rubber Co., B. F. Goodrich Co., and Minnesota Mining & Mfg. Co.

Table 4-20 lists glues which are used for metal bonding and their resistances to water and bacterial attack.

The strength of the bonded joint depends not only upon the strength of the materials joined and of the adhesive, but also upon the adherence between the adhesive and the adherend, and the geometric configuration of the joint.

Two factors which influence adhesion are shrinkage of the adhesive on hardening and the difference in the thermal expansion between the adhesive and the adherend. The greater the differential contraction between adhesive and adherend, the stronger is the induced shearing force at the interface.

According to J. W. McBain's tests, the strength of the adhesive layer varies with the inverse of the thickness. This may be explained by (1) the fact that as the thickness of the adhesive layer is reduced, the cumulative effects due to shrinkage are lessened; (2) the restraint afforded by the adherend is more pronounced in the thin layer, preventing reduction of the cross-sectional area; and (3) the thinner the adhesive layer, the less the probability of flaws. Figure 4-78 shows the variation of tensile strength with thickness of adhesive.

In a lap joint, the differential straining between the adhesive and the adherend causes the development of non-uniform stresses at the interface, there being a stress concentration at each end of the lap. Plastic flow in the adhesive, however, has a relieving effect on the peak stresses of the lap joint. Under plastic flow, the highly stressed ends deform and allow the load to be spread more equally throughout the joint. This is similar to the action of riveted joints where the highly stressed end rivets deform and allow for a more equally distributed load between all the rivets in the joint. Adhesives of rigid, non-yielding character do not exhibit this stress-relieving quality.

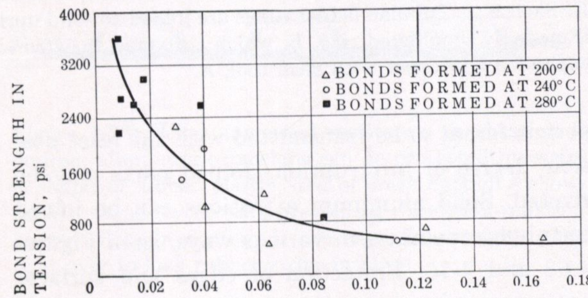


Figure 4-78: Variation of tensile strength with thickness of adhesive.

A symmetrical double-lap joint is not subject to bending due to non-coincidence of load and, there-

TABLE 4-20: WATER AND BACTERIAL RESISTANCES OF METAL-BONDING ADHESIVES

ADHESIVE	MATERIALS JOINED	RESISTANCE TO WATER	RESISTANCE TO BACTERIAL ATTACK
Casein latex	wood to metal	not resistant to water	attacked by bacteria
Ethoxyline resins Phenol Formaldehyde Acetal	wood to metal rubber to metal metal to metal	good resistance to boiling water	not attacked by bacteria
Resorcinal Formaldehyde	rubber to metal	indefinite resistance to boiling water	

fore, is stronger than a single-lap joint. See the comparison, Figure 4-79.

Assuming adherends of sufficient strength to sustain the imposed loading, failure of the joint would occur in the adhesive layer. This failure will take place at the point of highest stress. A high stress concentration factor (ratio of highest to mean stress) means that the stress at the ends of the lap are high, and these stresses may very well limit the load capacity of the joint. The stress concentration factor is smaller for lap joints with the following characteristics: (1) Short overlap, (2) thick adherends, (3) thick adhesive layer, (4) low adhesive stiffness as compared to adherends, (5) flexible members.

Item (3) may seem to contradict previous statements regarding the desirability of thin adhesive layers; but both statements are correct. The adhesive layer is stronger when it is thinner, but the joint has a lower stress concentration factor when the adhesive layer is thicker. A delicate balance must be struck between the two extremes for optimum results.

When designing a lap joint, the thickness of the adhesive layer is not considered since all joints will be made in accordance with specifications supplied by the adhesive manufacturer, and the thickness of the layer will therefore remain the same. The length of overlap and width of joint are the variables which are considered. Table 4-21 shows testing methods and typical strengths of adhesive joints. The latter depend not only on the type of adhesive, but sometimes also on the method of curing.

As can be seen, the peeling or cleavage strength of bonded joints is relatively low. Where the joint

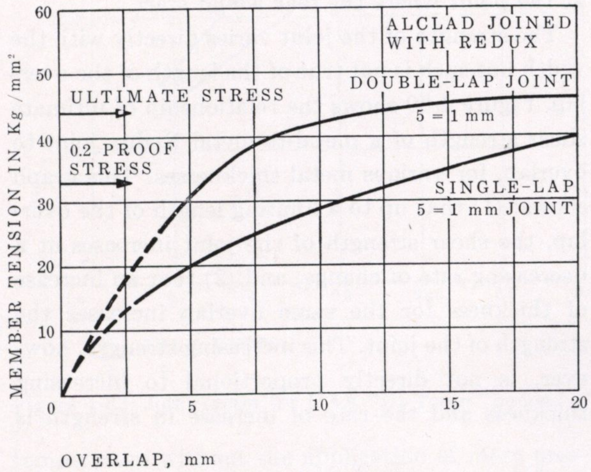


Figure 4-79: Comparison between experimental curves for the strength of single and double-lap joints.

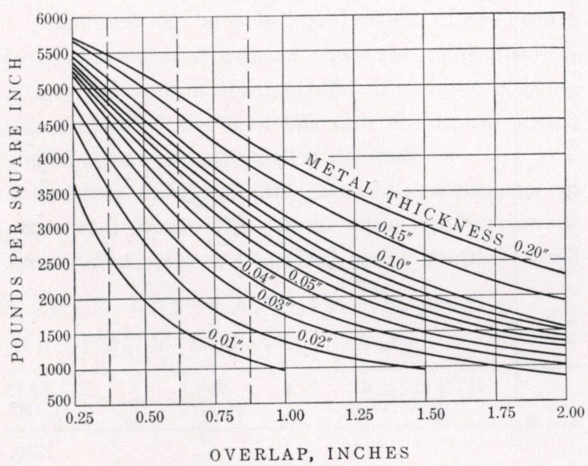


Figure 4-80: Relation of ultimate shear strength, metal-to-metal Redux joints, according to overlap and metal thickness. (From de Bruyne Nomogram) Engineering Laminates by G. H. Dietz, John Wiley.

TABLE 4-21: TESTING METHODS AND TYPICAL STRENGTHS OF ADHESIVE JOINTS

MECHANICAL PROPERTY	TESTING METHOD	DIRECTION OF FORCE APPLIED	MAXIMUM
Tensile Strength	Pulling apart two blocks	Perpendicular to adhesive film	7000 psi
Shear Strength	Pulling apart strips	Parallel to adhesive film	5000 psi
Stripping Strength	Tearing or peeling one piece from another		10–65 lbs/lineal inch

is loaded in such a manner that peeling or cleavage might occur, it is necessary to use a rivet or bolt at the point where the tear would start.

The strength of the joint varies directly with the width but such is not true of the length of the overlap. Figure 4-80 shows the relationship of ultimate shear strength of a metal-to-metal Redux joint to overlap, for various metal thicknesses. This graph shows: (1) that up to a limiting length of the overlap, the shear strength of the joint increases at a decreasing rate of change; and (2) that an increase of thickness for the same overlap increases the strength of the joint. This increasing strength, however, is not directly proportional to increasing thickness and the rate of increase in strength is not the same for different laps.

Figure 4-80 is characteristic of the overlap-strength and the thickness-strength relationships for all adhesives. Numerical values, of course, depend on the type of adhesive. It is, therefore, incorrect to state that a glue will give a breaking strength of so many psi. DeBruyne has used a term called the "joint factor" which, for a given type and thickness of adhesive and a given adherend, is the quantity determining the degree of stress concentration. This quantity is the square root of the adherend thickness divided by the length of overlap and is expressed: $\frac{\sqrt{s}}{l}$

If the adhesive and curing conditions are held

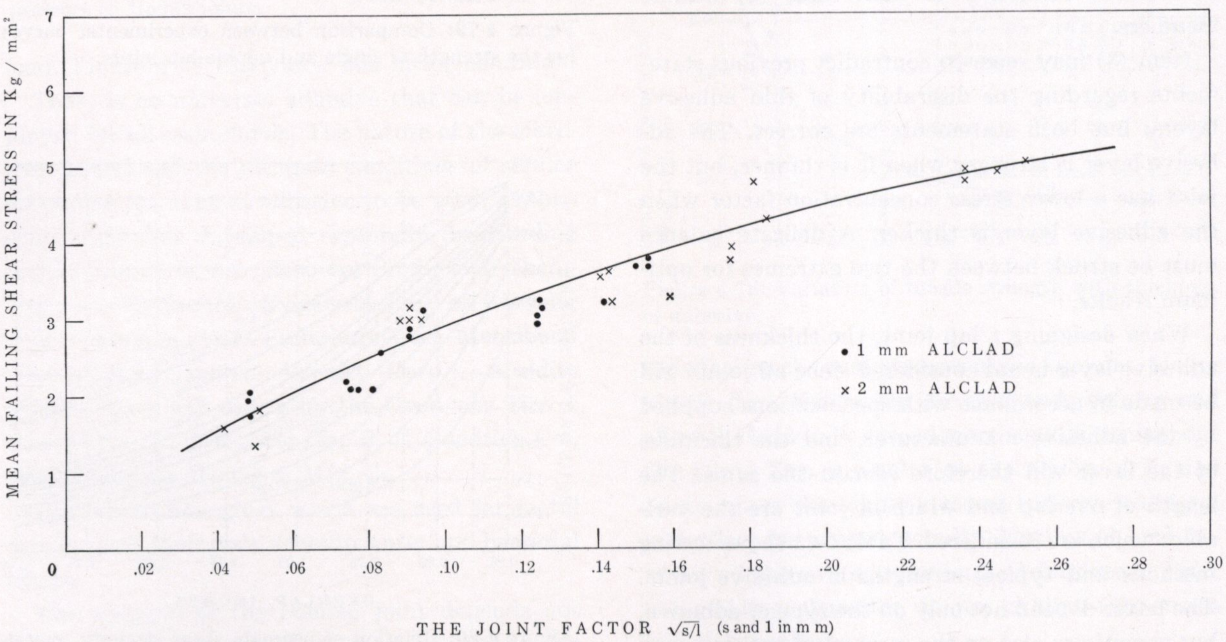


Figure 4-81: Apparent shear stress plotted against joint factor. Tests on simple lap joints of alclad aluminum made with "Redux," (National Luchtvaart Laboratorium, Amsterdam, Report No. M 1275, Figure 15, 1948). (From "Adhesion and Adhesives" by N. A. DeBruyne; Elsevier Publishing Co.)

constant, varying only the adherend thickness and the length of overlap, a curve of shear strength against joint factor may be plotted. From such a curve, the designer, for a given joint factor, can determine the strength of the joint. Conversely, for a certain joint strength, the designer can find the proper joint factor and thereby determine adherend thickness and length of overlap. Figure 4-81 shows a graph of shear strength versus joint factor for metal-to-metal joints made with Redux. Graphs such as this, for commonly used adherends, should be obtained as an aid to the proper design of lap joints. Where an adhesive has been especially designed for use at elevated temperatures, separate plots should be made for different temperature conditions. Figure 4-82 shows such a plot for NAA "Hi-Temp".

It is also apparent that since there is an infinite number of combinations of adherend thicknesses and joint overlaps which will give the same joint factor, the designer must be careful in determining the adherend thickness. Too thin a section may result in stresses which exceed the yield strength of the adherend whereas too thick an adherend may result in a design which is uneconomical.

Table 4-22 shows maximum laps and maximum shear loads for 1-inch wide test specimens of various thicknesses of Alclad 2024–T4.

Tests conducted by the National Advisory Committee for Aeronautics on bonded and riveted sheet stringer panels have shown that the sheets of riveted panels buckled at an average stress 40 percent below that of the sheets of the bonded panels. This may be explained by the fact that because of the wider area and continuity of contact between the sheet and stringer in the bonded panel, there is a greater effective width of sheet. Inter-rivet buckling was also eliminated.

Should a rivet or bolt fail, it can easily be located and replaced. The inability, at present, to readily locate failures or unbonded areas has been a deterrent to the greater use of adhesives. Another factor which has somewhat restricted the use of adhesives for metal bonding has been the requirement for the application of heat and pressure. As stated by F. Chapman, "For bonding metal to metal, the ideal adhesive would be one that could be used at room temperature without the application of more pressure than is required to bring the surfaces into contact and which, in a reasonably short time, would give an assembly that, on testing to destruction, resulted in complete metal failure."

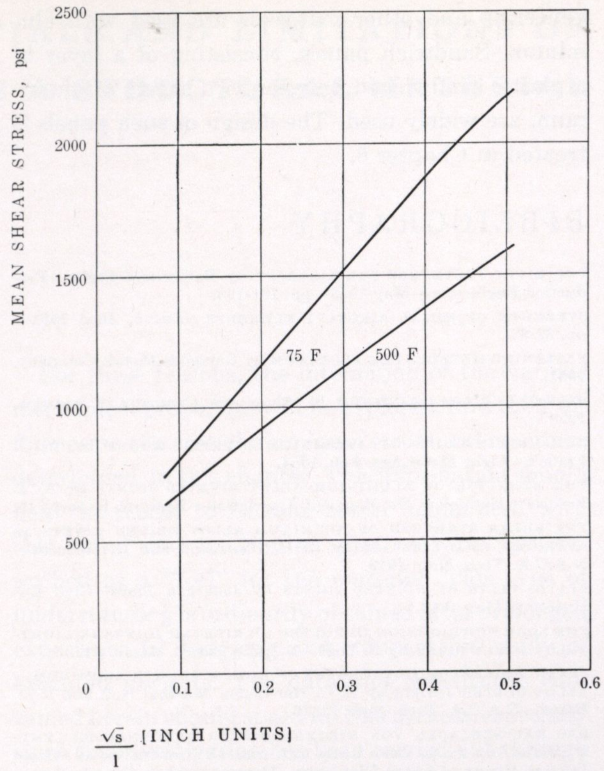


Figure 4-82: Joint factor for NAA "Hi-Temp" bonds.

Inasmuch as the bonding strength of aluminum to a non-metal is greater than the aluminum-to-aluminum combination, a thin rubber layer is sometimes inserted between the two aluminum sheets where maximum strength is desired.

Bonding of aluminum, especially aluminum to non-metal assemblies, finds wide application in architecture where plastics, cork, rubber, wood

TABLE 4-22: LAP LIMITS AND MAXIMUM SHEAR LOADS

GAUGE INCH	LAP INCH	STRENGTH POUNDS
.032	.7	1190
.045	1.1	1660
.051	1.3	1890
.064	1.5	2370
.081	2.1	3000

veneering and other materials are used with aluminum. Sandwich panels, consisting of a layer of a plastic sandwiched between two sheets of aluminum, are widely used. The design of such panels is treated in Chapter 6.

BIBLIOGRAPHY

POP RIVET FASTENERS FOR AIRCRAFT by Bailey and Ergler—Production Engineering, May 1953—pp. 191-198.

STRENGTH OF METAL AIRCRAFT ELEMENTS—ANC-5, June 1951—pp. 82-92.

FASTENING METHODS FOR ALUMINUM by Reynolds Metals Company, 1951.

RIVETING ALCOA ALUMINUM by Aluminum Company of America, 1953

BEHAVIOR STUDIES OF ALUMINIUM RIVETED JOINTS by A. J. Francis—Light Metal Age, Feb. 1954.

THE BEHAVIOR OF ALUMINIUM ALLOY RIVETED JOINTS by A. J. Francis—Aluminium Development Association—Research Report #15.

THE SHEAR STRENGTH OF ALUMINUM ALLOY DRIVEN RIVETS AS AFFECTED BY d/t RATIOS by E. C. Hartmann and C. Wescoat—N.A.C A. Tech. Note #942.

STATIC TESTS OF RIVETED JOINTS by Jonathan Jones—Civil Engineering, May 1940.

THE LOAD DISTRIBUTION IN BOLTED OR RIVETED JOINTS IN LIGHT-ALLOY STRUCTURES by F. Vogt—N.A.C.A. Tech. Memo. #1135.

STATIC AND FATIGUE STRENGTHS OF HIGH STRENGTH ALUMINUM-ALLOY BOLTED JOINTS by E. C. Hartmann, Marshal Holt and I. D. Eaton—N.A.C.A. Tech Note #2276.

DAS KALTSCHLAGEN VON NIETEN GROSSER DURCHMESSER (ENTWICKLUNGEN IN KANADA BEIM BAU DER ARVIDA-BRUECKE) (Cold Driving Rivets of Large Diameters—Development in Canada during Construction of the Arvida Bridge)—Aluminium Suisse, May 1954.

WELDING AND RIVETING LARGE ALUMINUM STRUCTURES—A Symposium—Aluminium Development Association, November 1951.

NEUE UNTERSUCHUNGSERGEBNISSE AN LEICHTMETALL-KLEBEVERBINDUNGEN (Recent Test Data on Bonded Light Metal Joints) by K. Krekeler—Aluminium, April 1953.

SOLID STATE BONDING OF ALUMINUM AND NICKEL by S. Storchheim, J. S. Zanbrow, and H. H. Hansner—Journal of Metals, Sept. 1953, p. 1081.

FESTIGKEITSUNTERSUCHHUNGEN AN GEKLEBTEN LEICHTMETALL-VERBINDUNGEN (Strength Tests on Bonded Light Metal Joints) by P. Brenner and A. Matting—Aluminium, January 1954.

TESTS OF BONDED AND RIVETED SHEET-STRINGER PANELS by Leonard Mordfin and I. E. Wilks—N.A.C.A. Tech. Note #3215.

ADHESION OF MATERIALS TO METALLIC SURFACES—Science Library Bibliogr. Series No. 727 (Supplement to No. 561), February 24, 1954.

THE PROPERTIES AND USES OF METAL ADHESIVES by R. A. Johnson —Sheet Metal Ind. 31, Oct. 1954, pp. 829, 835, 841.

ENGINEERING LAMINATES by A. G. H. Dietz—John Wiley and Sons, Inc., New York, pp. 89-167.

ADHESION AND ADHESIVES by N. A. DeBruyne and R. Honwink—Elsevier Publishing Company.

ADHESIVE BONDING OF METALS by George Epstein—Reinhold.

STRUCTURAL ADHESIVES—Lectures given at Cambridge—Lange, Maxwell and Springer, Ltd.

FORCE FIT IMPROVES BRAZED ALUMINUM JOINTS by B E. Brennan —The Iron Age—December 10, 1953, pp. 148, 149.

CLOSER TOLERANCE ALUMINUM PARTS BRAZED IN SALT BATH by Wm. J. Rudolph—Materials & Methods, January 1954, pp. 96-99.

VENTILATORS FRAME BRAZED TO ALUMINUM ROOFS—Metal Progress 65, June 1954, pp. 156-160.

ULTRASONIC SOLDERING AND TINNING OF LIGHT ALLOYS by A. E. Williams—Mechanical World, March 1953, pp. 124, 125.

ULTRASONICS, THE ANSWER TO ALUMINUM SOLDERING by Leo Walter—Materials and Methods, July 1953, pp. 59-61.

IMPROVE YOUR SOLDERING WITH NON-CORROSIVE FLUX by W. S. Gale—The Iron Age, September 3, 1953, pp. 115-119.

ULTRASONICS IMPROVE SOLDERED JOINTS IN ALUMINUM by J. J. Obrzut—Iron Age 173, June 24, 1954, pp. 97-99.

NEW TIN-DEPOSITED FLUX FOR SOLDERING ALUMINUM by Donald C. Burch and Robert L. Simpkins—Materials & Methods, August 1954, pp. 86-89.

SOLDERING ALUMINUM: A SURVEY OF PROGRESS by J. C. Bailey and J. A. Hirschfield—Research 7, August 1954, pp. 320-326.

THE WELDING OF THICK PLATES OF HIGH-STRENGTH ALUMINUM ALLOYS by D. C. Martin, M. I. Jacobson and C. B. Soldrich—The Welding Journal—April 1953, pp. 161s-171s.

THE WELDING OF NON-FERROUS METALS by E. G. West—John Wiley and Sons, Inc., New York.

WELDING ALUMINUM by Reynolds Metals Company, 1953.

WELDING ALCOA ALUMINUM by Aluminum Company of America, 1954.

PRESSURE WELDING ATTRACTS INTEREST by Charles Bruno and G. W. Birdsall—Steel—June 8, 1953, pp. 90, 91.

SOME CONSIDERATIONS ON WELDABILITY OF ALUMINUM ALLOYS by J. Koziarski—The Welding Journal—October 1953, pp. 970-986.

FLASH WELDING THE ALUMINUM ALLOYS by Lester F. Spencer—Industry & Welding—November 1953, pp. 66-68, 71, 72.

WELD ALUMINUM DIE CASTINGS WITH INERT ARC PROCESS by Robert Haslip—Industry & Welding—January 1954, pp. 33-36.

AUTOMATIC WELDER MAKES ALUMINUM PIPE PRACTICAL by F. L. Resen—Oil & Gas Journal 52—March 15, 1954, pp. 79, 80.

AN ALL WELDED ALUMINUM ALLOY SUPERSTRUCTURE—Light Metals, April 1954—p. 118.

THE PRACTICE OF ARGON ARC WELDING by H. Walser—Aluminium Suisse 4, May 1954.

WELDING ALUMINUM TUBING: TWO NEW PROCESSES—Aluminium News, May 1954—p. 7.

DISSIMILAR METALS CAN BE FLASH-WELDED—Steel 134, June 28, 1954—pp. 132-133.

HOW ABOUT WELDING THE ALUMINUM ALLOYS? PROCEDURE FOR SPOT WELDING by Lester F. Spencer—Welding Engineer 39—June 1954, pp. 51-55.

THE WELDING of 356–ALUMINUM ALLOY CASTINGS by W. S Tenner —Welding Journal 33, June 1954—p. 620.

PROCESS ADJUSTMENT IN INERT-GAS-SHIELDED ARC WELDING by E. B. LaVelle—Welding Journal 33, June 1954—pp. 553-560.

APPROXIMATE SHEAR STRENGTHS OF ALUMINUM FILLET WELDS—Welding Engineer 39, July 1954.

SPOT WELDING THIN ALUMINUM by I. W. Johnson—Welding Journal 33, Aug. 1954—pp. 759-762.

WELDING ALUMINUM SHEET by F. C. Geibig—Welding Journal 33, Aug. 1954—pp. 784-788.

WELDING ALUMINUM ALLOY STRUCTURES—Light Metals, Aug. 1954 —pp. 250-253.

SPOT WELDING OF HIGH STRENGTH ALUMINUM ALLOYS: EFFECTS OF WELDING VARIABLES ON WELD QUALITY by H. E. Dixon and J. E. Roberts—Brit. Welding Journal 1, Aug. 1954—pp. 351-370.

THE "TWIN-ARGON" WELDING PROCESS by J. A Donelan—British Welding Journal, Sept. 1954—pp. 403-408.

CALCULATION OF WELD JOINTS by C. G. J. Vreedenburgh—Prod. Eng., Sept. 1954—p. 330.

IMPROVEMENT IN THE ELECTRIC ARC WELDING OF BOLTS, STUDS, AND THE LIKE by J. L. Sarazin & M. Moneyron—B. P. 717, 512, comp spec's published Oct. 27, 1954.

SPOT WELDING ALUMINUM WITH SINGLE PHASE EQUIPMENT by J. W. Kehoe and D. R. McCutcheon—Welding Journal 33, Oct. 1954—pp. 966-986.

WELDING ALUMINUM ALLOY STRUCTURES by J. E. Tomlinson—Light Metals, Oct. 1954—pp. 334-336.

CHAPTER 5: POTENTIALS AND LIMITATIONS OF ALUMINUM AS A STRUCTURAL MATERIAL

The usefulness of a material is determined by the relationship of its relevant mechanical properties to the cost. Economically and technically sound applications will only be possible if the function of the product is consistent with the optimum performance of the material. The finding of the most suitable application and the defining of the optimum range of the material is of basic concern to the designer.

This chapter is devoted to the discussion of basic relationships which will serve to point up some of the potentials and limitations of aluminum *as a structural material.*

5.1 RELATIONSHIP OF PHYSICAL CHARACTERISTICS AND COST

Aluminum is extremely versatile and adaptable. Its applicability within the building industry is very broad, practically covering the entire field. It is used as a decorative material and trim, as an exterior or interior finish and protection. Windows and doors are made of aluminum. It finds application in heating, ventilating, air-conditioning and piping installations. It is used for electrical conductors and lighting fixtures.

Load-carrying capacity and rigidity are of fundamental importance in all applications, although they may be of only secondary concern with respect to the specific function of the product. Trim, windows, spandrel panels, even ducts and bus bars must have strength and rigidity.

Aluminum is also an important structural material and it is playing an increasingly important role in this application. Consistent and intelligent use of aluminum structures offers many benefits to engineers, architects and the industry itself.

For these reasons, the interaction of the various mechanical properties will be explored, and their influence on the cost of aluminum structural members determined, in this chapter. This information should help the reader to become better acquainted with this metal and to acquire what may be best described as a "feel" for the material. This type of understanding is ordinarily obtained after prolonged experience in designing and comparative study of executed projects. The data and conclusions contained herein should speed up this process, especially since the investigation has been carried out through comparison with the veteran building material, structural steel. The use of this comparison was not motivated by any desire to increase the competition between these two metals. In fact, it will be shown that there are distinct areas within which each material performs to its best advantage.

Mechanical properties of materials can be related conveniently to their densities whenever comparisons of efficiency in terms of dead-load, live-load ratio of the structural members are indicated. This relationship is also meaningful if cost comparisons are made between two materials, and if the cost is measured per unit weight. Such ratios between strength and weight are usually referred to as *strength-weight ratios.* Similar relationships can be found between the rigidity or elasticity of a structure and its weight.

In numerical examples, values pertaining to *aluminum alloy 2014-T6* and *structural steel ASTM designation A-7* will be used. Furthermore, strength characteristics considered will be in terms of allowable stresses. For alloys 2014-T6, the ASCE Specifications (see Appendix to Chapter 7), and for structural steel the AISC Specifications, are used to

TABLE 5-1: MECHANICAL PROPERTIES, DENSITY, COST AND RELATED QUANTITIES OF ALLOY 2014-T6 AND STRUCTURAL STEEL A 7

	UNIT	2014-T6	A 7
Density γ	$\frac{\text{lbs}}{\text{in.}^3}$	0.101	0.283
Factor of Safety at Yield Point Stress		2.41	1.75
Allowable Tensile Stress and Extreme Fiber Stress in Bending f	psi	22,000	20,000
Modulus of Elasticity E	psi	10.6×10^6	29×10^6
Coefficient of Thermal Expansion α_t	in./in./°F	12.8×10^{-6}	6.7×10^{-6}
Average Cost per lb of Structural Sections c	cents/lb	47.4	7.48
$\left(\frac{f}{\gamma}\right)$ Basic Strength-Weight Ratio	in.	21.8×10^4	7.07×10^4
$\left(\frac{E}{\gamma}\right)$ Basic Elasticity-Weight Ratio	in.	10.5×10^7	10.2×10^7
$(E\gamma)$	$\frac{\text{lbs}^2}{\text{in.}^5}$	1.07×10^6	8.21×10^6
Cost per cu in. $(c\gamma)$	$\frac{\text{cents}}{\text{in.}^3}$	4.79	2.12
Ratio of Cost of Aluminum to Cost of Steel of Equal Weight C_a/C_s		6.34	

obtain allowable or working stresses. The use of the allowable instead of ultimate or yield stress is indicated since the purpose of the comparisons is to provide an approximate guidance in the practical design of aluminum structures governed by cost criteria. The pertinent characteristics of the two materials are given in Table 5-1.

The results of the comparisons are illustrated in a series of graphs. These are not intended for purposes of design of aluminum alloy members or the "conversion" of steel members into aluminum. Rather, it is hoped that these graphs, together with other chapters of this volume, will convince the reader of the complete uselessness of the "conversion" approach. The engineer must learn to think and work in terms of the material used and this chapter is designed to aid him in making this transition from a well known material to a less familiar one.

The graphs show the ratio of weights of structural elements of equal capacity in both materials and indicate a range of efficiency in relation to the span. When the weight of an aluminum structure is only about 16 percent that of a steel structure of equal capacity, then the *cost of the material* in both is roughly equal. This weight ratio is therefore the approximate demarcation in terms of economic span of structural elements for the materials compared. On the other hand it must be remembered that the total cost of the structure is made up of numerous components. While the cost of the material itself is an important component, the cost of fabrication and erection labor is equally significant but unfortunately not subject to very precise numerical comparisons. Nevertheless the following approximation will give some idea of its influence:

It is assumed that the fabrication and erection labor is in direct proportion to the volume of the metal. For example, the fabrication and erection cost of an aluminum girder should be approximately three times that of a steel girder of equal cross-section and equal weight, since the length of the aluminum member (due to the lower density of the material) will be three times that of the steel member, and therefore it may have three times as many connections and other details requiring fab-

rication and erection labor. For these conditions, the total cost including material and labor is given in Table 5-2.

TABLE 5-2: COST OF STRUCTURES IN CENTS PER POUND

MATERIAL	MATERIAL COST	LABOR COST	TOTAL COST
Steel	7.48	7.5–15.0	15.0–22.5
Aluminum	47.40	22.5–45.0	69.9–92.4

The assumption that the labor cost is a function of the volume is unfavorable to aluminum. In many instances the cost of labor may turn out to be related to the weight, which would result in lowering the total cost estimate for aluminum. Nevertheless Table 5-2 indicates that even for this conservative assumption it may not be necessary to achieve an extreme weight reduction in aluminum. Instead of 16 percent, it may be sufficient to produce aluminum structures weighing about 25 percent of similar steel structures. Since an aluminum structure which is geometrically identical to a steel structure weighs only 35.6 percent of the steel structure, an additional reduction of 10 percent should be possible in many instances. In subsequent sections of this chapter, the criteria and limitations of weight savings and their further implications will be examined.

5.2 THE STRUCTURAL RATIO

The problem of structural design is a complex one. Generalized discussion of such a subject must of necessity avoid considerations of certain details which ordinarily enter into the design of structures. For this reason, the results of this study can be no more than approximations and are to be used as a general guide only, indicating certain trends which, if followed, will lead toward the desired economy of design.

The numerical data given in the graphs should be modified by additional considerations. Data referring to girders, for instance, do not take into consideration effects of shear and local buckling. In many instances, these factors may lead to important modifications. Nevertheless, it is safe to assume that the results arrived at, even neglecting such factors, are of use by indicating general design principles pertaining to aluminum in terms of a more familiar material, namely structural steel.

The most important mechanical property of aluminum in which it differs greatly from steel, besides its lower density, is its lower modulus of elasticity. For this reason, elastic stability considerations (buckling) enter more frequently into the design of aluminum structures than those of structural steel. In this respect, a design in aluminum may be closer to that in light-gauge steel than in structural steel.

The various strength-weight ratios, therefore, depend very strongly on the geometric properties of the structural members under consideration. This applies primarily to members subject to buckling but members in bending are also affected, as will be demonstrated. While the strength-weight ratios serve a useful purpose for economic comparison of structural materials, they may be misleading if economic considerations are not paramount. If minimum weight in itself is an objective, the weight-strength ratio is a more suitable measure. This distinction is important because one is not the reciprocal of the other.*

In order to measure the economic efficiency of a structural element in terms of the span (L), its weight per unit of length (w), the concept of the structural ratio is used here, symbolized by the letter R. Superscripts s and a refer to aluminum and steel. The structural ratio is defined, and its characteristics are given as follows:

"*Structural Ratio*" (strength-weight or elasticity-weight ratio) symbolized by the letter R is a property of a structural element built of a specific material and has the form of

$$R = L\frac{g + w}{g} \qquad (1)$$

It has the dimension of length and it represents the span (or length or height) limit; that is, the maximum span of the structural element within given design and code limitation. As the span limit is approached, the ratio of the dead load (the weight of the structure itself) to the total load approaches

*WEIGHT-STRENGTH ANALYSIS OF AIRCRAFT STRUCTURES, F. R. Shanley, McGraw-Hill, 1952—p.7.

unity, and the superimposed load approaches zero

$$\lim_{w \to o} L = R = L_{max} \qquad (2)$$

at which span the structure is not capable of supporting superimposed loads.

In principle therefore it is possible to support a superimposed load on a span which is unattainable with a structure having a lower structural ratio

$$L^a{}_{max} > L^s{}_{max} \quad \text{if } R^a > R^s \qquad (3)$$

Of two geometrically identical structures supporting identical superimposed loads, the one possessing a higher structural ratio will be of lower weight

$$\left(\frac{g_a}{g_s}\right) = \frac{1 - \dfrac{L}{R^s}}{\dfrac{R^a}{R^s} - \dfrac{L}{R^s}} < 1.0, \text{i.e. } g_a < g_s \text{ if } R^a > R^s \qquad (4)$$

The structural ratio is a function of two sets of variables:

—Variables depending on the physical characteristics of the material and on the use of the structure: Allowable stresses, allowable deflections, modulus of elasticity, density. These are generally determined by the material and therefore are constants.

—Design parameters, representing the designer's choice in the method of supporting the structure, the use of determinate or indeterminate structures, and the like, as well as certain geometric characteristics such as span—depth ratio, slenderness ratio, and so on.

The weight of a structure, therefore, can be controlled effectively through the choice of these design parameters and, in principle, a structure can always be designed in such a manner that its weight and cost (provided that the latter is in proportion to the weight) are equal or less than that of another similar structure possessing a lower structural ratio.

The above procedure, however, can only be extended to certain practical values of the design parameters due to limitations on the maximum size or depth (fabrication and space considerations) or minimum thickness (fabrication, corrosion danger).

In aluminum structures, due to favorable production, fabrication and non-corrosive properties of the material, most of the above practical limits are lower than in steel structures. For this reason, a high structural ratio in aluminum can be fully exploited.

The specific structural ratios under consideration are defined as follows:

R_1, *Structural ratio for tensile strength:* Length of a vertical member of uniform cross-section suspended at the top which will be stressed to the maximum allowable tensile strength under its own weight.

R_2, *Structural ratio for elongation:* Length of a vertical member of uniform cross-section suspended at the top which will be stretched (elongated) to an allowable limit of elongation under its own weight.

R_3, *Structural ratio for bending strength:* Span of a transverse member of uniform cross-section and shape supported at both ends, which will be stressed to the allowable extreme tensile fiber stress in bending under its own weight.

R_4, *Structural ratio for deflection:* Span of a transverse member of uniform cross-section and shape supported at both ends, which will deflect to the allowable limit of deflection under its own weight.

R_5, *Structural ratio for compression:* Length of a vertical member of uniform cross section and shape braced at both ends, which will be stressed to the allowable column compressive stress under its own weight.

5.3 TENSION MEMBERS

The axially loaded tension member is the simplest structural element and it will therefore be used for the proof and derivation of equations 1, 2, 3 and 4 presented in the previous section. Similar procedures are used for the derivations in the case of members in bending and columns, but because of the elementary nature of the proof they will not be repeated in the sections dealing with these members.

STRENGTH:

The weight (g) of the tension member per unit length is given by

$$g = A\,\gamma \qquad (5)$$

where A is the cross-sectional area and γ the density of the material. The maximum total load W on a member subject to an axial load P is

$$W = P + Lg \qquad (6)$$

if the maximum tensile stress at the top of the member is given by

$$f = W/A \tag{7}$$

where the maximum tensile stress is equal to the allowable stress f. Inserting Equation 5 and 6 into Equation 7 and rearranging, the required weight per unit length of the member is obtained

$$g = \frac{P}{(f/\gamma)\text{-}L} \tag{8}$$

inserting

$$R_1 = f/\gamma \tag{9}$$

which is the structural ratio for tensile strength, the following relation is obtained

$$R_1 = L\frac{w + g}{g} \tag{10}$$

where $w = P/L$ (the superimposed load per unit length). The numerical value of R_1 for steel and aluminum is obtained from Equation 9.

$R_1^s = 5{,}900$ feet
$R_1^a = 18{,}200$ feet
and therefore
$R_1^a > R_1^s$

The ratio of the weight r_1 of an aluminum tension member to that of a steel tension member of identical length and load capacity is given in non-dimensional form by

$$r_1 = \frac{1 - L/R_1^s}{n_1 - L/R_1^s} \tag{11}$$

where $n_1 = R_1^a/R_1^s$ and the fraction L/R_1^s is the ratio of the length of the members compared to the span limit (i.e. structural ratio) of steel in tension. It is obvious that the weight ratio r_1 will decrease (i.e. will become more favorable to aluminum) if the length of the member increases. It will reach the demarcation line of equal cost at

$$r = \frac{\text{cost of steel per unit weight}}{\text{cost of aluminum per unit weight}} = .157 \tag{12}$$

when $L/R_1 = .61$, i.e. when the length of the member is 61 percent of the span limit of steel in tension. For structural applications this is far beyond practical dimensions.

Reduction of the weight ratio could also be obtained by increasing the value of n to that of R_1^a. In this case the structural ratio contains only physical constants (without design parameters) which are usually not under the control of the designer. Aluminum tension members therefore are usually less economical than steel members. The structural ratio can be increased by using higher strength alloys and this is indicated for the design of tension members.

ELONGATION:
The elongation (ΔL) of an axially loaded tension member is given by

$$\Delta L = \frac{g\,(L/2) + P}{EA} \tag{13}$$

where E is the modulus of elasticity of the material. If the allowable strain $\frac{\Delta L}{L}$ is given, the structural ratio becomes

$$R_2 = 2\left(\frac{\Delta L}{L}\right)\left(\frac{E}{\gamma}\right) \tag{14}$$

and the weight ratio is given by

$$r_2 = \frac{1 - L/R_2^s}{n_2 - L/R_2^s} \tag{15}$$

where

$$n_2 = \frac{R_2^a}{R_2^s} = \frac{E_a}{\gamma_a}\frac{\gamma_s}{E_s} \approx 1 \tag{16}$$

and therefore

$$r_2 \approx 1 \tag{17}$$

i.e. aluminum and steel tension members will always be of equal weight if the capacity is limited by allowable strain. In this case, however, the allowable capacity in strength

$$\frac{P_a}{P_s} = \frac{3 - L/R_1^s}{1 - L/R_1^s} \gg 1 \tag{18}$$

will be considerably higher in aluminum. For short lengths of tension members (which is the case in most practical applications), the strength capacity of the aluminum member will be nearly three times that of the steel member. On the other hand, in case of members of equal maximum allowable capacity, the elongation of the aluminum member will always be higher. Where the members are short, the elongation of the aluminum member will be about three times that of the steel member.

5.4 TRANSVERSE BENDING

STRENGTH: The structural ratio in transverse bending for girders of constant cross-section (ignoring elastic stability considerations) is given by

$$R_3 = (f/\gamma)\,(h/L)\,(k/\alpha) \tag{19}$$

where h/L is the depth span ratio of the girder,

k^* is the form factor in bending and α is the maximum moment coefficient.

In this expression (h/L) and α are design parameters and therefore subject to the choice of the designer within a relatively wide range of values, while k is variable only within a much smaller range. The allowable extreme fiber stress f and the density γ are constant for each material. The design parameters in most practical cases fall within the intervals:

$\frac{1}{24} \leq h/L \leq \frac{1}{8}$

$\frac{1}{16} \leq \alpha \leq \frac{1}{8}$

and therefore the structural ratios have the following ranges

$687 \text{ ft} \leq R_3{}^s \leq 4{,}122 \text{ feet}$

$2{,}083 \text{ ft} \leq R_3{}^a \leq 12{,}498 \text{ feet}$

These ranges indicate the effect of the choice of the design parameters: The lower limit is obtained with smallest depth-span ratio and the moment coefficient of a simply supported girder with uniform loading. The upper limit is obtained with certain types of continuous girders of a relatively great depth. At the spans corresponding to the structural ratio, no superimposed load can be carried but for a given ratio of girder weight to total load, the maximum allowable span can be obtained

$$L_{max} = R_3 \frac{g}{g + w} \tag{20}$$

For most practical applications, the ratio of dead load to total load cannot be less than $\frac{1}{5}$ and therefore the limit of the span where the girder is still able to carry a practical amount of superimposed loads can be estimated by multiplying the structural ratios by $\frac{1}{5}$. In certain steel bridge structures these ranges are already approached.

The ratio of the weights of aluminum and steel girders of identical capacity and span are given by

$$r_3 = \frac{1 - L/R_3{}^s}{n_3 - L/R_3{}^s} \tag{21}$$

where

$$n_3 = \frac{R_3{}^a}{R_3{}^s} = \left(\frac{h_a}{h_s}\right)\left(\frac{\alpha_s}{\alpha_a}\right)\left(\frac{f_a\ \gamma_s\ k_a}{f_s\ \gamma_a\ k_s}\right) \tag{22}$$

The weight ratio here depends not only on the span but also on the value of n_3 which is variable.

If the design parameters are equal for both steel and aluminum girders

$$n_3 = n_1 \tag{23}$$

and the weight relations are those of tension members. If on the other hand an aluminum girder can be designed in which it is practicable to have a greater depth than in a steel member, then

$$n_3 > n_1 \tag{24}$$

The effect of the increased depth on the weight relations are shown on Graph 5-1. If the depth of the aluminum girder is at least twice that of the steel girder, the cost of the material will be less in aluminum for all spans. As was shown previously, it may not be necessary to achieve equal material cost to obtain equal total cost of structures.

It should be noted that in many instances it is practicable to use greater depth for aluminum girders than for steel members. This is possible since lighter gauge material can be employed because of its better corrosion resistance, and also because larger aluminum girders are still relatively easy to handle owing to their low weight.

Increased structural ratio can also be obtained by designing continuous girders wherever practicable. Because of the higher cost of the material itself, the significant weight savings which may be achieved in this manner will be justified, even at increased fabrication cost.

DEFLECTION: The structural ratio for the deflection of girders of symmetrical uniform cross-section is given by

$$R_4 = \left(\frac{d}{L}\right)\left(\frac{E}{\gamma}\right)\left(\frac{k}{2\ \alpha\ \beta}\right)\left(\frac{h}{L}\right)^2 \tag{25}$$

where d is the allowable deflection and β is the deflection coefficient.*

In this case the structural ratio differs from the previous instances primarily by the fact that it is a function of the second power of the depth-span ratio and is therefore more sensitive to variations in the depth of the girder. If both steel and aluminum girders are of identical cross-section, the structural ratio of both materials will be equal with good approximation and both girders will have approximately identical weights. In this instance, however,

* The form factor k is related to the section modulus (Z) of the member by the relation $Z = kAh$. For WF sections and some plate girders and trusses $k = 0.35$ with good approximation.

* The meaning of β is given by $d = \beta L \frac{ML}{EI}$ where M is the bending moment.

the capacity of the aluminum girder in terms of strength will be higher than that given by Equation 18 for tension members.

In many problems it is desirable to obtain girders which operate at full efficiency both with respect to allowable extreme fiber stress and allowable maximum deflection. Such girders are characterized by

$$h/L = \frac{f}{E} \frac{2\beta}{(d/L)} \qquad (26)$$

The particular depth span ratio for $(d/L)_{allowable} = 1/290$ and the allowable extreme fiber stress given in Table 5-2 is obtained

for steel A7 $h/L = 1/24$

for 2014-T6 $h/L = 1/8$

This relation is significant because it shows that aluminum girders operating at full efficiency with respect to bending strength and deflection should have three times the customary depth-span ratio of steel girders. On the other hand, if both steel and aluminum girders have the same span, but the depth of the aluminum girder is three times that of steel, then the ratio of load-bearing capacities is given by

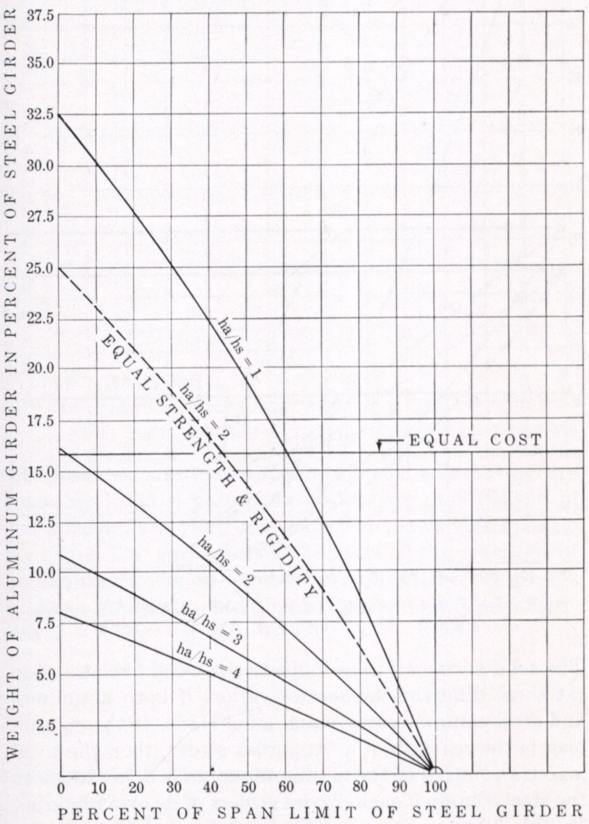
$$W_a/W_s = \frac{9 - L/R_3^s}{1 - L/R_3^s} > 9 \qquad (27)$$

The ratio will increase with increasing span. If the depth-span ratio of the aluminum girder is less than $1/8$ then the design will be governed by the allowable deflection-span ratio and the member will operate below the maximum allowable fiber stress. If it were loaded to the maximum strength, it would exceed deflection limitations. If we now compare the weight of such an aluminum girder with a steel girder of equal span and identical manner of support, the ratio of the weights is given by

$$r_4 = \frac{1 - L/R_3^s}{(h_a/h_s)^2 - L/R_3^s} \qquad (28)$$

Graph 5-1 indicates the weight relationship for $(h_a/h_s) = 2$ (dotted line). It should be remarked that effects equivalent to depth increase can be accomplished by the use of continuous girders or rigid connections as in the case of girders governed by strength only.

GRAPH 5-1:
GIRDER WEIGHT
COMPARISON FOR VARIOUS RATIOS OF THE DEPTH (h_a/h_s) OF ALUMINUM GIRDER TO STEEL GIRDER
(Equal Superimposed Load on Girders)



The weight of aluminum girders compared to steel girders of identical capacity decreases with increasing span. (*Solid line on graph*).

Increasing the depth of an aluminum girder relative to a steel girder also results in reduction of relative weight. The points on the curve below the "equal cost line" represent those spans at which aluminum is more economical than steel. If the depth of the aluminum girder is at least twice that of the steel girder, its cost will be lower for any span length.

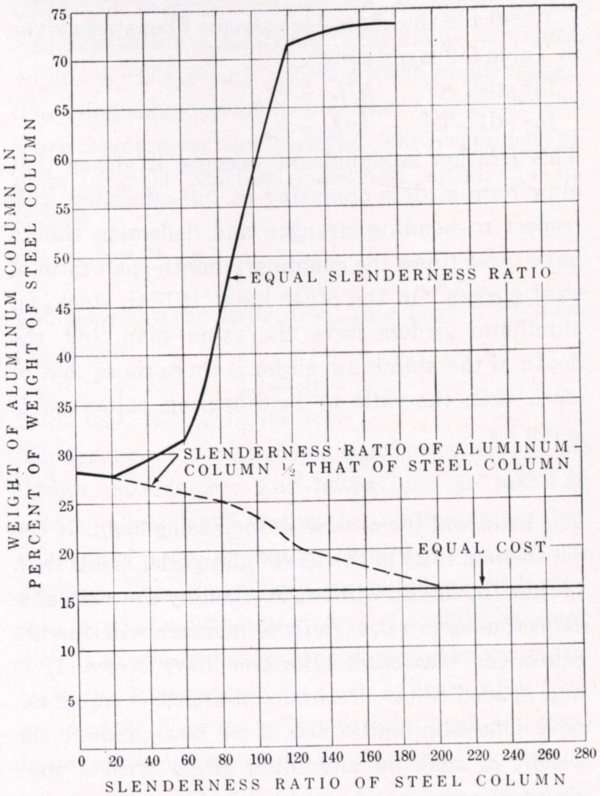
If in addition to equal capacity, equal deflection is required, the weight of the aluminum girders will be higher than if strength alone governs. (*Dashed line*).

5.5 COMPRESSION

In the analysis of compression members, columns as a specific example, it is evident that the type of column formula used has a great bearing on the conclusions reached. For steel columns, the AISC specifications employ a formula based on the Johnson parabola for slenderness ratios of less than 120; for larger values, a modified Rankine formula is used.

GRAPH 5-2: COLUMN WEIGHT COMPARISON

(Equal Axial Load on Columns)

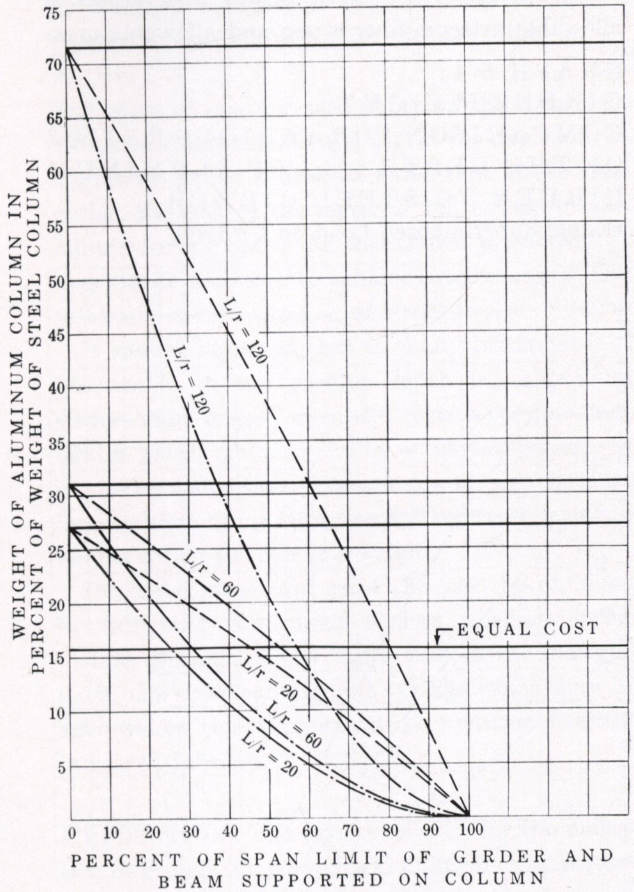


The relative weight of the aluminum column increases with increasing slenderness ratio, if both columns maintain equal radii of gyration. Under these conditions the cost of aluminum columns is higher than of steel columns. (*Solid line on graph*).

If the slenderness ratio of the aluminum column is lower, the relative economy of aluminum increases with increasing slenderness. If the radius of gyration of the aluminum column is twice that of the steel column, equal cost is approached at very slender columns only. (*Dashed line*).

GRAPH 5-3: COLUMN WEIGHT COMPARISON

(Aluminum and Steel Columns of Equal Slenderness Ratio)

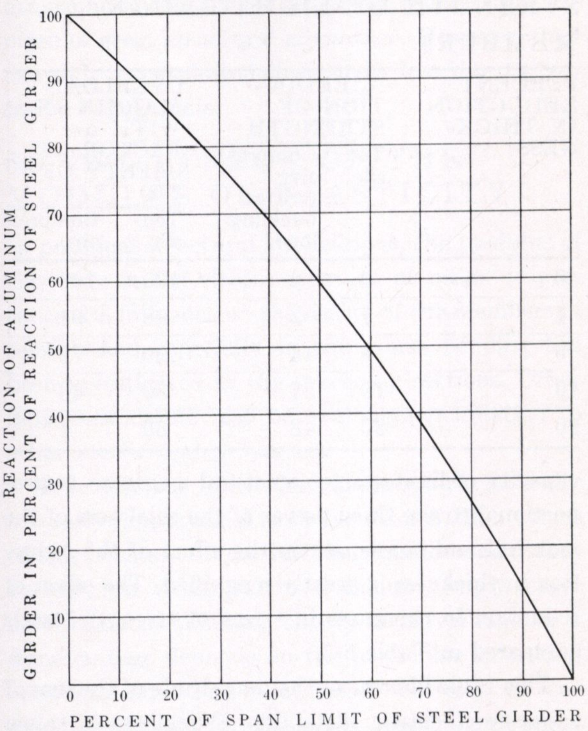


The *solid horizontal* lines indicate the weight relationship (at three different slenderness ratios) if both aluminum and steel columns carry equal axial loads. If the column load is the reaction of a supported girder, then the total load transmitted to the aluminum column is less than to the steel column if each carries girders of its own material. In this instance, the relative weight and cost of the aluminum column decreases with increasing girder span, i.e. column spacing (*dashed line*). The situation is even more favorable if the entire superstructure is made of aluminum (*dash-dotted line*). The comparison is made for girders and beams of equal capacity, depth and superimposed load, supported in identical manner.

ASCE specifications for alloy 2014-T6 use tangent-modulus column curves with a factor of safety of 2.5 and for ordinary conditions assume a partial restraint at the ends. This curve has a cut-off point at $(L/r) = 20$, after which the basic allowable stress of 22,000 psi governs, while the ASCE sets the maximum stress at 17,000 psi at $(L/r) = 0$. These properties of the column formulas naturally influence the obtainable weight and cost savings strongly, and the use of different column curves may lead to different conclusions.

In practical applications in one-story structures, the weight of the column is negligible compared to the superimposed loads and is expressed by the

GRAPH 5-4:
FOUNDATION LOAD COMPARISON
(Equal Superimposed Load on Girders)



The load transmitted to foundations or columns is considerably lower if aluminum girders are used instead of steel girders. The relative economy increases with increasing span. The graph shows the ratio of the reactions of aluminum girders to identically supported steel girders with equal superimposed loads, spans, depths and capacities.

relationship that is shown below

$$g = P \frac{1}{R_5 - L} \tag{29}$$

where P is the superimposed axial load.

If the length L of the column is short compared to R_5, the following approximation is obtained

$$g = P \frac{1}{R_5} \tag{30}$$

and the ratio of weight of aluminum column to steel column is

$$r_5 = \frac{R_5{}^s}{R_5{}^a} = \frac{1}{n_5} \tag{31}$$

and the strength-weight ratio in compression is of the form

$$R_5 = \frac{F_c}{\gamma} \tag{32}$$

where F_c is the allowable compressive stress, which is a function of the slenderness ratio (L/r). In Graph 5-2, values of r_5 are given as a function of (L/r) plotted from the previously mentioned column formulas. The value of r_5 decreases with decreasing (L/r) and reaches its minimal value of 0.27. Even at this weight ratio, the cost of the aluminum column is 1.7 times as much as of the steel column.

Obviously this relationship can be materially improved by using a lower slenderness ratio for the aluminum column than for the steel column. This is essentially equivalent to the increase of depth of aluminum girders as discussed in the preceding section. Graph 5-2 illustrates the effect of the slenderness ratio on column weights.

In all-aluminum structures the superimposed load on the aluminum column is lower than on the steel column, resulting in further reduction of the column weight and increased economy.

5.6 CUMULATIVE WEIGHT SAVINGS

Due to their lighter weight, it is evident that aluminum structural elements will transmit reduced reactions to supporting members. The total load W carried by the girder is obtained from Equation 1

$$W = L\,(g + w) = R_3\, g \tag{33}$$

and the ratio of the reactions of identically loaded aluminum and steel girders of equal capacity is given by

$$\frac{W_a}{W_s} = r_3\, n_3 \tag{34}$$

and is shown on Graph 5-4 for equal span and depth of both girders. The reduction of the transmitted load results in lighter foundation and lighter column loads. The weight of columns in turn also decreases, and the reduced weight ratio (r_5') of an aluminum column supporting an aluminum girder to a steel column supporting a steel girder is given by

$$r_5' = r_3\, \frac{n_3}{n_5} \tag{35}$$

provided that the superimposed loads are equal and the girders are of identical span.

Further lightening of the load on columns is achieved if the aluminum girders themselves support aluminum secondary framing members (purlins or beams or deck).

In case of square panels of span L and superimposed load p per unit area, the total load transmitted to the column is further reduced if aluminum is used throughout and the weight ratio of the columns is

$$r_5'' = r_3^2 \frac{n_3}{n_5} \qquad (36)$$

Equation 36 is similar to 35 but the effect of the reduction is represented by the second power of r_3, *indicating the cumulative effect of savings obtainable in all-aluminum structures.* (See Graph 5-3.)

5.7 THE EFFECT OF CORROSION RESISTANCE

The implications of corrosion resistance are quite obvious in terms of lowered maintenance cost. There are, however, a number of less obvious advantages which can be utilized by fully exploring this particular property. One major advantage comes from the fact that corrosive attack limits the minimum thickness of light-gauge steel shapes due to loss of cross-sectional area.

The loss in tensile strength of thin sheets and sheet-metal sections is directly proportional to the loss in thickness due to corrosion. In aluminum, this loss seldom exceeds .002-inch as is pointed out in Chapter 3. This loss even in thin aluminum sheets (.020-inch thick) thus usually does not exceed 10 percent even after prolonged exposure. The corresponding loss in .064-inch aluminum would only amount to about 3 percent. This amount of reduction in structural applications with a factor of safety of 2.00 would still permit an 80 percent overloading above the design load, if other factors do not contribute to loss of capacity. This overload margin is ample for all structural applications.

The reduction of load carrying capacity of light-gauge members, however, cannot be properly measured in terms of tensile strength loss only because of the governing influence of elastic stability failure in compression or shear. Under these criteria, the

TABLE 5-3: EFFECT OF REDUCTION OF THICKNESS, DUE TO CORROSION, ON THE STRENGTH OF LIGHT-GAUGE MEMBERS

PERCENT REDUCTION IN THICKNESS	% REDUCTION OF STRENGTH		OVERLOAD MARGIN IN % WITH A FACTOR OF SAFETY OF 2.00	
	Tensile	Compressive (critical buckling load)	Tensile	Compressive
0	0	0	100	100
1	1	3	98	94
5	5	14	90	72
10	10	27	80	46
20	20	48	60	4

capacity of light-gauge structural members is proportional to the third power of the thickness of the material and consequently the effect of the reduction in thickness is greatly magnified. The effect of reduction in thickness in terms of strength loss is compared in Table 5-3.

This table illustrates the magnitude of the loss of capacity if elastic instability (buckling) is taken into consideration. For this and similar reasons, the use of light-gauge structural steel members below a thickness of .076-inch (14 gauge) is usually not recommended, while aluminum sections of half this thickness and less are used with satisfactory results. This substantial reduction of the lower limit of the thickness of aluminum light-gauge sections compared to cold-rolled steel sections can lead to an important weight and cost advantage.

The depth of penetration of corrosion does not depend on the thickness of the section. This leads to a second consideration at the opposite extreme of sizes. Aluminum shapes used as girders or columns of equal or even lesser weights than corresponding steel members have a larger volume and therefore greater thickness. This results in a further reduction of strength loss over and above the inherent corrosion resistance of the material.

Under favorable circumstances, the effect of corrosion on strength can be neglected, and this may permit the design and fabrication of details which

are not accessible to repainting and maintenance. Hollow sections, box sections, multiple web members with openings which leave the interior open to atmospheric contact but otherwise inaccessible, are often of great structural advantage. However, they can only be exploited if strength loss due to corrosion is negligible.

5.8 THE EFFECT OF THE MODULUS OF ELASTICITY

In practical structural applications, the modulus of elasticity is the elastic constant of major importance. Its influence on the design of the members in tension and especially in transverse bending has been investigated in the preceding sections. Other influences should also be evaluated in relation to other mechanical properties.

Deformations: Since deformations are generally inversely proportional to the value of E, high values of this constant imply low deformations and, conversely, low values (as in aluminum) imply larger deformations. Whether this is an advantage or a disadvantage depends on the particular structural considerations. The relationship between E, the modulus of elasticity, the strain, and the unit stress is expressed by the familiar formula

$$E\left(\frac{\Delta L}{L}\right) = f \qquad (37)$$

which indicates that in problems requiring a specific deformation, the induced stress will be lower for materials with lower modulus of elasticity. There are two such instances which are of practical significance. These are *assembly stresses* (often referred to as locked-in stresses) and *stresses due to settlement or rotation of foundations.*

In the first instance, the stress is induced by inaccuracy of the fit or by initial distortion of the members which are assembled. The induced stress is additive to the stresses from exterior loads. In the second case, the stresses are induced by foundation displacement or rotation. These stresses are also superimposed on the live load and dead load stresses. In both instances, due to the 1:3 ratio of the elastic moduli of aluminum and steel, *these stresses in the aluminum structure will be only one-third as high as in a similar steel structure.*

In connection with foundation displacements, a further potential reduction of stresses is possible due to the lower foundation pressure obtainable in aluminum structures because of reduced dead loads.

Temperature Stresses: A somewhat similar situation exists with regard to temperature stresses. The magnitude of this stress due to a temperature differential Δt is generally expressed by the following relationship

$$f = \Delta t\ (\alpha_t E) \qquad (38)$$

where α_t is the coefficient of thermal expansion of the material. For constant temperature differential, the stress is proportional to the quantity $\alpha_t E$. While the coefficient of expansion of aluminum is nearly twice as high as that of steel, the product with the modulus of elasticity is lower

For aluminum $(\alpha_t E) = 135.7$

For steel $(\alpha_t E) = 194.3$

Thermal stresses in an aluminum structure therefore will be about only 70 percent as high as in a comparable steel structure.

Elastic Behavior: In a number of applications, the elastic behavior of a structure under dynamic loading is of importance. Under these types of loadings, such as impact and vibration, the structure is to transmit a certain amount of kinetic energy while maintaining the allowable stress. The total weight of material required to accomplish this is inversely proportional to the strain energy which can be stored in the structure. The expression for the strain energy per unit weight has the form

$$\frac{f^2}{2E\gamma} \qquad (39)$$

Substituting the corresponding numerical values, the ratio of weights required to absorb a given amount of kinetic energy by tension is

$$\frac{g_a}{g_s} = \frac{\left(\dfrac{2E\gamma}{f^2}\right)_a}{\left(\dfrac{2E\gamma}{f^2}\right)_s} = 0.108 \qquad (40)$$

This value illustrates one of the outstanding qualities of aluminum, the ability to absorb impact and other dynamic loadings. Compared with structural steel, aluminum is nearly 10 times as effective in the elastic range.

The lower dead load of aluminum structures also expresses itself as reduction in the design of structures subject to inertia forces such as seismic motions. In this case, the total shear induced by seismic shocks is directly proportional to the mass of the building, which is lower in aluminum structures, thus indicating further potential economies.

Elastic Stability (Buckling): Probably the most important influence of the modulus of elasticity is in determining the critical load of systems governed by elastic stability (buckling). The most common case of this is the buckling of columns (Section 5.5 in this discussion). Due to the use of empirical or semi-empirical column curves, this relationship is somewhat obscured. But the classical Euler equation

$$\mathrm{P}_{cr} = \frac{\pi^2 \, (EI)}{L^2} \tag{41}$$

clearly shows that the critical buckling load of long hinged columns is in direct proportion to the value of (EI); that is, the stiffness of the member. Since the magnitude of E for aluminum is about one-third that of steel, it appears that the capacity of an aluminum column will be only one-third of the capacity of a geometrically identical steel column. Following a reasoning similar to that used in the foregoing sections, the ratio of the weights of aluminum and steel columns of equal capacities and lengths can be expressed. The weight of the column (neglecting its effect on the critical load) is

$$g = \frac{2 \, P_{cr}}{\pi^2 \, k \left(\dfrac{E}{\gamma}\right) \left(\dfrac{h}{L}\right)^2} \tag{42}$$

Observing that the expression $\left(\dfrac{E}{\gamma}\right)$ is approximately equal for aluminum and steel, the ratio of the weights is obtained

$$\left(\frac{g_a}{g_s}\right) = \left(\frac{h_s}{h_a}\right)^2 \tag{43}$$

which indicates that, by proper choice of the geometric parameter, the weight ratio can be adjusted to almost any desired value, and the value of this ratio is independent of the length of the member.

The above case referred to the critical load with respect to overall instability of the member. In the design of light-gauge members, the load limit may be reached by local instability of its elements, which are essentially thin plates.

The expression for the critical compressive or shear load is generally expressible in the form

$$P_{cr} = \frac{AEt^2}{b^2} \times \text{constant} \tag{44}$$

where the constant depends on the type and distribution of stresses and the geometric properties of the plate.

The cross-sectional area of the plate of thickness t and width b is

$$A = bt = \frac{g}{\gamma} \tag{45}$$

The weight ratio then is obtained by

$$\left(\frac{g_a}{g_s}\right) = \frac{(b/t)_s}{(b/t)_a} \tag{46}$$

The weight ratio, therefore, is controlled by the choice of the geometric parameter (b/t), that is, the flat-width ratio of the plate. *To obtain equal cost, the flat-width ratio of the aluminum member should therefore be about 40 percent that of the steel member.*

It should be noted that there are instances of light-gauge design where buckling limitations can be eliminated entirely. This occurs, for example, in the Wagner beam, in which the web is allowed to buckle under shear loading, and stress transfer is effected through tension in the buckled web and through compression in the stiffeners. In this application, it is essential that the web be made of sufficiently thin material. This is only possible if non-corrosive properties of the material permit the full utilization of the tensile strength of the thin web. While this type of structure is not at present used in building structures, it has often been applied in airframe construction and is especially suitable for aluminum.

The disadvantage of a lower elastic modulus as regards critical buckling stress can also be overcome by the use of stiffeners. The idea of stiffened thin plate and shells is fully accepted in fuselage design of aircraft and can be applied to advantage for all structural purposes. In aluminum it is possible to produce, by the extrusion process, plates with integral stiffeners, which should be of interest in building structures (see Figure 3-10).

5.9 CONCLUSIONS

Because the cost of aluminum is considerably higher than that of structural steel at the present time, there are ranges of application defined by these cost considerations. To extend this area of application to its limit, certain facts have to be taken into consideration and specific recommendations governing the design of aluminum structures should be observed. These facts and recommendations, which are essentially the results and applications of the above listed conclusions (aluminum alloy 2014-T6 versus structural steel ASTM designation A7) can be summarized as follows:*

TENSION MEMBERS: If design is *limited by load capacity only*, the *weight* will be no more than 32.4 percent that of an equivalent steel member; the *cost* will be no more than twice that of the steel member.

Both *cost and weight decrease with increasing length* of member, but *equal cost* is achieved only at a length of 3600 feet *which is beyond ordinary applications.* Aluminum tension members should be made of *highest strength alloys* to achieve economy.

If elongation is limited, the *weight* will always nearly *equal* that of the equivalent steel member.

GIRDERS AND BEAMS governed by *load capacity*:

Weight: Not more than 32.4 percent that of the equivalent steel member, the percentage rapidly reducing with increasing span.

Cost: For *members of equal depth*, cost of aluminum becomes lower beyond about 60 percent of the span limit of steel. *If the depth* of the aluminum girder is at least *twice* that of the steel member, *cost of the aluminum girder can always be lower than for steel.*

Both *cost and weight percentage reduce* with (1) increasing span, (2) increasing depth, (3) when member is continuous or rigidly connected, and (4) when secondary members (purlins, deck) are also in aluminum.

GIRDERS AND BEAMS limited by *deflection*: Members of equal depth will have *equal weight*, and the *weight can be decreased* by any amount either by increasing depth or by using continuous or rigidly connected members.

If members are *stressed to maximum* allowable fiber stress and *deflection is simultaneously limited*, the depth-span ratio of an aluminum girder must be *three times* that of the steel girder; otherwise the aluminum member must be made continuous or rigidly connected with secondary members also in aluminum. *The capacity of such aluminum girders, however, is at least nine times that of the steel member.*

COLUMNS:

Weight of aluminum columns *is at least* 27.5 percent of steel columns, both carrying equal axial load and having equal slenderness. Weight percentage *increases* with increasing slenderness.

Cost of these columns is always higher than for steel columns. This cannot be reduced substantially by the use of higher strength alloys as in tension members. *Aluminum columns should have a lower slenderness ratio; that is, a higher radius of gyration.*

Weight and Cost, however, can be reduced *substantially* if the aluminum column supports an all-aluminum superstructure. *The savings in weight and cost increase with increasing column spacing.*

FRAMING SYSTEMS (using hot rolled or extruded beams, girders and columns):

Cost of the system can *be brought below that of steel* systems provided all or most of the following design methods are employed:

—Members have a maximum depth consistent with other criteria.

—Continuous or rigidly connected framing is employed, taking full advantage of the possibility of designing special extruded connecting elements and other more complex details not usually employed in structural steel constructions, but frequently used in aircraft design. It should be remembered that temperature stresses and secondary stresses due to inaccurate fit in these indeterminate structures are lower than in steel structures.

—Because of high cost per pound coupled with advantageous fabricating and forming character-

* It is important to note that the effects of shear and local buckling have been omitted in this discussion in the interest of simplicity. See second paragraph, Section 5.2 on Page 131.

istics and corrosion resistance, built-up aluminum members with economical distribution of the material (also removal of excess material in form of cuts and openings) should be used. This includes box girders, multi-web girders and similar structures which may have parts inaccessible to painting. The favorable corrosion-resistant characteristics of the material should also be exploited so that the minimum thickness is determined only by structural considerations.

—If primary members (columns, main girders or trusses) are of aluminum, it is essential that the maximum of secondary elements (decks, purlins, wall panels, ceilings and the like) also be in the same material.

—Planning of buildings should take advantage of the fact that both aluminum girders and columns operate with increasing efficiency at large bay spacings. This will also effect a substantial reduction in loads on the foundation, resulting in further savings.

—Low total weight of the structure greatly reduces seismic loads. The high resiliency of aluminum should be fully exploited in designs where impact and dynamic loads are encountered.

BIBLIOGRAPHY

MAGNESIUM ALLOY STRUCTURES by S. K. Ghaswala—I.A.B.S.E. Publications, 1953—p. 95.

BASIC CONCEPTS OF THE STRUCTURAL THEORY OF ALUMINUM ALLOYS by S. K. Ghaswala—I.A.B.S.E. Publications, 1952—p. 571.

ALUMINIUM—WERKSTOFFE IM BRUECKENBAU (Aluminum in Bridge Construction) by O. Liebing—Aluminum, 29. Jahrg. 1953—½—pp. 46-49.

ALUMINUM AS A STRUCTURAL MATERIAL by Paul Weidlinger—Progressive Architecture, September 1948—pp. 77-84; continued October 1948—pp. 89-92.

WEIGHT-STRENGTH ANALYSIS OF AIRCRAFT STRUCTURES by F. R. Shanley—The Rand Series, McGraw Hill, New York, 1952.

CHAPTER 6: STRUCTURAL DESIGN

Aluminum alloy, while relatively new for such structural uses as buildings and bridges, is actually the "traditional" material for airframes. For this reason, a wealth of information can be obtained on the behavior and the properties of such structural members. This chapter attempts to make this information available in a form which will be of direct use to structural engineers concerned with the design of buildings.

This is accomplished through the application of the ASCE Specifications for alloy 6061-T6, which is of moderate strength and high corrosion resistance, and alloy 2014-T6 which is of high strength. The design examples here are worked out in terms of the second of these alloys, but this does not imply a preference or a specific recommendation for the use of this particular material. In a great many applications the higher corrosion resistance of alloy 6061-T6, which eliminates the necessity of painting, will lead to more economical solutions. The ASCE Specifications may also be used for designing with other aluminum alloys which meet the strength and elongation requirements of the ASTM Specifications. In selecting a particular alloy, these three factors should receive paramount consideration:

—Strength
—Cost
—Corrosion resistance

The design examples presented here to illustrate the application of the ASCE Specifications are restricted to simple, conventional types of construction, with certain alternate design solutions proposed for particular structural members in order to indicate the direction where a departure from the ordinary structural steel practice may prove worthwhile. In this connection it should be pointed out that, while the fabrication cost of aluminum alloys is relatively low compared to the cost of the material itself, the economic feasibility of using very complex shapes and assemblies should be investigated carefully to avoid shifting cost factors from material into fabrication. While this danger is much less than is the case in steel structures, the designer should not lose sight of fabrication costs in his enthusiasm for weight saving. In this connection, the reader is referred to the pertinent paragraphs of the Preface and to the conclusions and recommendations of Chapter 5.

Special attention was given in the design examples to certain design details which are not explicitly covered by the ASCE Specifications. Where necessary, additional recommendations are included to facilitate the solution of such problems.

Sections 6.4 and 6.5 cover the design of aluminum sandwich constructions. This type of structure, ordinarily not included in standard texts on structural engineering, is detailed here because of its increasing importance and application in contemporary buildings. As in the case of more conventional structural elements, most of the readily available information pertains to aircraft applications. The information presented in this chapter has been simplified and made usable for the building designer.

6.1 STRUCTURAL ELEMENTS

The design of structures in aluminum alloys follows along the lines of structural steel design with a few important variations. These variations are essentially due to the differences in physical characteristics, the most significant being the lower values

of the elastic constants, the lower density and the specific stress-strain relations. The implications of these variations, especially in terms of weight economy, are discussed in Chapter 5. The following brief review is concentrated on direct structural implications. The actual details of design procedure are illustrated and discussed in Design Examples 1 and 2.

FACTOR OF SAFETY: The ASCE Specifications set the factor of safety for tensile stress at 2.33 and 2.41 respectively for alloys 6061-T6 and 2014-T6. This factor of safety is with respect to the yield strength and is more conservative than the 1.75 factor of safety used by AISC Specification for structural steel ASTM-A7. This is justified by the fact that the spread between yield and ultimate tensile strengths is smaller for aluminum alloys than for structural steel. The factor of safety with respect to the critical buckling stress in columns and in the compression flanges of beams and girders is set at 2.5 by the ASCE Specifications.

STRESS-STRAIN RELATIONS: In referring the factor of safety to the yield strength, it should also be remembered that, in contrast to structural steel, aluminum alloys do not exhibit a clearly defined yield point on the stress-strain curve, but show a gradual transition. The yield point is arbitrarily defined at a permanent strain of 0.2 percent. In this connection it should also be recalled that, while many of the design procedures are based on the assumption of a linear stress-strain relationship within design stresses, the tensile proportional limit is usually measured at a permanent strain equal to 0.0001. This also indicates that beyond this point the standard value of the modulus of elasticity is not applicable. This fact has significance in gaging the precision of the result of design computations in indeterminate structures.*

ELASTIC CONSTANTS: The effect of the relatively low modulus of elasticity is very strongly felt in the design procedures used and constitutes the most significant departure from design practice in structural steel. The reader will note in the design examples and also in the ASCE Specifications (reprinted in the Appendix to this volume) that the investigation for various types of overall and local buckling stresses represents the major portion of design computations. This means that in the great majority of instances the critical buckling stress falls below the yield point stress of the elements.

This fact alone requires a different outlook on the design of aluminum alloy structures and, in this regard, the procedures employed are similar to those used in the design of light-gauge steel members. In working out aluminum alloy members, the designer is often required to satisfy simultaneously a much greater number of criteria than in the design of structural steel members. In the design of a simple I-section, in bending, for example, the designer will find it necessary to check and satisfy the following requirements:

1. Extreme tensile fiber stress: Check for tensile strength.
2. Compressive stress in flange: Check for lateral buckling.
3. Shear stress in web: Check for shear strength.
4. Moment of inertia: Check for deflection.
5. Shear stress in web: Check for local buckling.
6. Compressive stress in web: Check for local buckling.
7. Compressive stress in flange: Check for local buckling.

In structural steel, the designer would usually check only the first four of the above items. In addition to the seven items above, the design of connections requires correspondingly greater care. In case of welded designs, for instance, the allowable stress and the limit of the heat-affected zone need to be determined to establish the strength of the welded connection. (See Sections 4.1, 4.2).

The above examples probably illustrate quite effectively the increased complexity of the design methods. A certain amount of this added work load could be reduced by the preparation of design tables for standard structural sections. Unfortunately, at the present time only very little such standardization is available. Standard extruded or rolled structural sections usually follow the proportions established for structural steel and are

* ANC-5 BULLETIN: STRENGTH OF METAL AIRCRAFT ELEMENTS.

therefore inherently uneconomical for aluminum alloys inasmuch as the various elements will usually fail in local buckling long before overall failure or yield stress is reached, thereby preventing the full economical utilization of the material.* It is hoped that, with increasing use and demand, standardized I- and WF-sections suitable for aluminum alloys will be made available, at which time a great deal of the design data could be profitably represented in tabular form.

In this connection, it may be pointed out that further improvement in the design methods will be obtained if the inelastic range of the material is fully taken into account and the great reserve strength past the elastic limit is fully exploited. This procedure which, in the structural design of buildings, is being introduced both for reinforced concrete and structural steel, may also result in a more realistic criterion of strength for structures in aluminum alloys.

6.2 PRACTICAL CONSIDERATIONS

At the present time a number of all-aluminum structures have been executed which are both technically and economically satisfactory. Structural economy resulted, as is to be expected, mostly in larger spans. The theoretical reasons for this are discussed in Chapter 5. In this regard, bridges represent an interesting example. Studies by Liebing† in Germany indicate that aluminum alloy bridges should be more economical than bridges built of ordinary structural steel for spans above 426 feet. The following table shows three representative examples where the comparative weight of aluminum to steel (g_a/g_s) was available:

LOCATION	USE	YEAR COMPLETED	SPAN FEET	TYPE	g_a/g_s (%)
Grass River (N. Y.)	Railroad	'46	100	Girder	41.5
Sagueney (Canada)	Highway	'50	290	Arch	43.5
Clunie (Scotland)	Pedestrian	'50	173	Arch	36

* THEORY OF LIMIT DESIGN, J. A. Van Den Broek, John Wiley, 1948.
† ALUMINIUM-WERKSTOFFE FUER DEN BRUECKENBAU, Liebing, Aluminium, Jan./Feb. 1953.

These spans are relatively short for bridge construction: however, more significant results were obtained in English aircraft hangar structures. The 217-foot span Havilland Hangar in Hatfield weighs only about 14 percent of a comparable steel structure. When such significant material savings are achieved, there can be no question as to economic justification for aluminum at present price relationships. This hangar, which is 330 feet long with a clear height of 45 feet was erected in 13 hours with two 5-ton cranes. (See Figure 6-9, Page 148).

Experience and theoretical considerations indicate that it is desirable to increase the depth of aluminum alloy members above the usual dimensions employed with structural steel members. (See Chapter 5).

When this policy is translated into practical design details, it is important to consider all its implications:

Benefits:	*Limitations:*
1. Increased rigidity in plane of member (large I).	1. Increased depth of construction (large h).
2. Increased overall buckling strength in plane of member (large r).	2. Decreased local buckling strength (large b/t).
3. Decreased weight of flange.	3. Increased weight of web.
4. Decreased forces at moment connections.	4. Decreased thickness of material available for connections.

Other benefits and limitations than those listed above may have to be studied in individual problems, but most of the usual instances are covered by these points. The objective of the designer is to achieve optimal dimensions, balancing benefits against limitations. In practice, therefore, it is always advisable to compare various preliminary solutions in which essential design parameters, like the depth of the members, are varied. To fully exploit the potential benefits of the design policy, it is desirable to arrive at details which minimize the effects of the limitations. How this can be achieved will be illustrated in a few individual instances in the subsequent paragraphs. Before these particular examples are examined, two pertinent observations

Figure 6-1: The Grasse River Bridge, Massena, New York, includes a 100-foot span weighing 53,000 pounds, compared with 128,000 pounds weight for the adjoining steel spans.

Figure 6-2: Lifting the 100-foot aluminum span of the Grasse River Bridge.

Figure 6-3: Complete Grasse River Bridge showing the aluminum span.

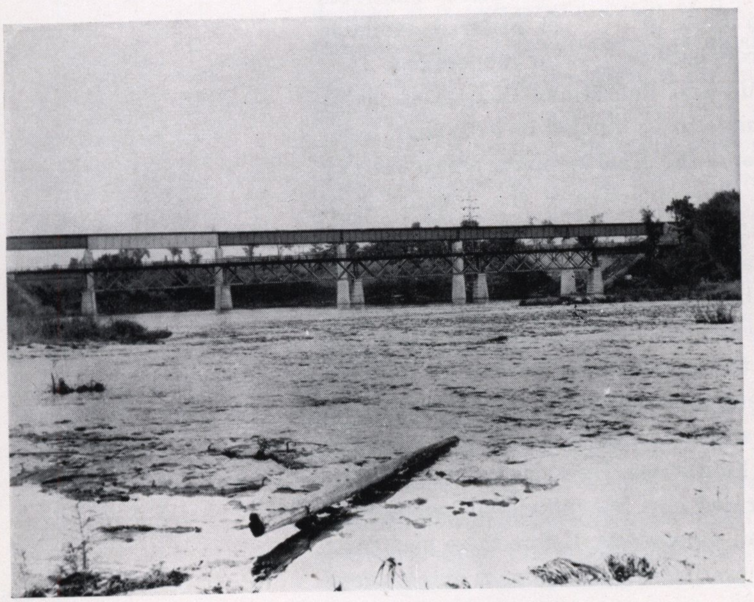
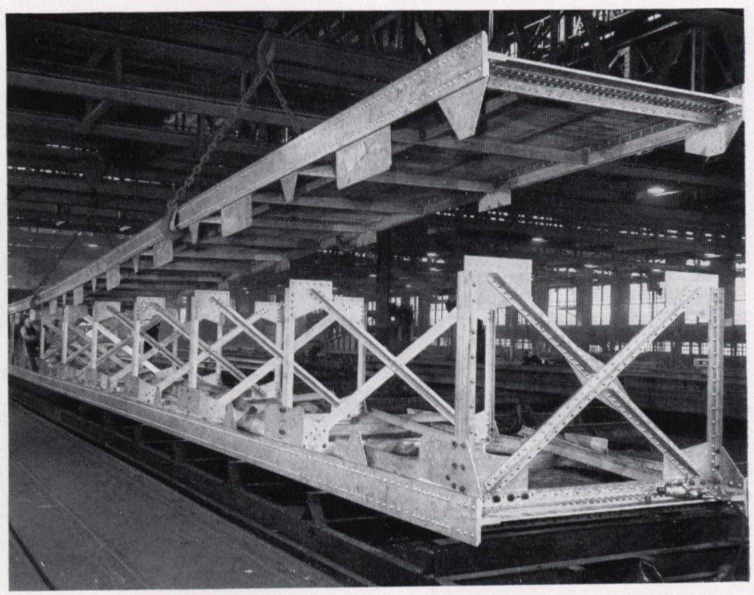


Figure 6-4: Fabrication of the Grasse River aluminum span.



should be made:

—Special details developed to take into account the many design requirements are often inherently complex. This may result in increased cost of fabrication, which should be balanced against potential savings in weight and material cost. The extrusion process makes possible the fabrication of these complex cross-sectional shapes at low cost.

—Consistent use of the most suitable details leads to an idiom peculiar to aluminum alloy construction. It points to a typical expression of the material, resulting in a recognizable "aluminum architecture" distinct from the architecture of other materials.

FLANGE DETAILS: Extruded shapes for the flange section of girders, beams, trusses and columns can be detailed to perform various functions.

Extruded stiffener lip serves to increase the critical buckling strength of the flange (Figure 6-10).

The flange can be formed to facilitate satisfactory lateral bracing of the flange by the deck (Figure 6-11).

The function of the flange can on occasion be fully or partially taken over by the deck itself (Figure 6-12).

The purpose of the above details is to develop very light flange sections possessing sufficient lateral and local buckling strength for use with deep girders and trusses.

The flange can also be formed to facilitate the connection of other elements or members:

A "T" section with deep extruded web permits the connection of verticals and diagonals in trusses without the use of gusset plates (Figure 6-13). Efficient connections to the web can sometimes be obtained if a double stem is used in "T" (Figure 6-14). This arrangement uses rivets in double shear and also permits symmetrical connection of the web plate, both of which are of importance if the web is of very light material. This double stem arrangment essentially replaces the usual double angle detail with a single member.

In girders supporting continuous beams, the

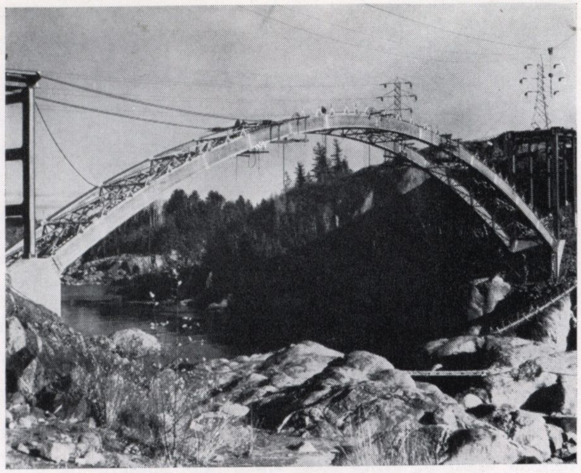


Figure 6-5: Arvida Bridge, Saguenay River, completed arch. The arch rise is 47 feet 6 inches; span is 290 feet.

Figure 6-6: Erection of Arvida Bridge.

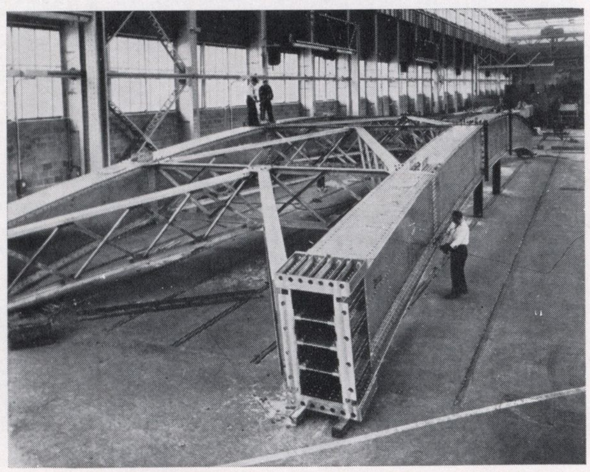


Figure 6-7: Fabrication of Arvida Bridge.

Figure 6-8: Clunie Footbridge. This unpainted aluminum span over the River Tummel, Pitlochry, Perthshire, has central span of 172.5 feet. Each side span is 69 feet. Clear width between parapets is 6 feet 6 inches.

function of the cover plate, providing for the continuity of the beam, can be taken over by the girder flange by forming the flange "T" of the girder with a double flange (Figure 6-15). This arrangement is efficient because it provides a symmetrical and double shear connection between the beam and girder. Furthermore, the girder flange at the connection is in a state of biaxial stress and therefore the principal stress directions remain longitudinal and transverse to the direction of the flange.

If the maximum stress in the beam flange is not larger than in the girder flange (which is the usual case) the girder need not be increased beyond what would be required for the girder alone. Inasmuch as for biaxial stress (without superimposed shear) the principal shearing stress is one half of the larger normal stress (if these are of opposite sign as the case would be at the top flanges), it will be always within the allowable shear stress for the material if it is designed to resist the longitudinal stresses.

Some of these details can be combined into a single extruded flange section as illustrated in Figure 6-16.

WEB DETAILS: As the depth of girders is increased, it is usually found that a very large percentage of the material will have to be used in the web, leading to lowered efficiency in bending. Small rolled or extruded sections, for instance, may use less than 20 percent of the total material in the web, while in deep sections the web can take up more than half of the weight. Under these circumstances to maintain the efficiency of the section, the thickness of the web is kept at a minimum leading to local shear or bending instability. The obvious way to overcome these difficulties is to use trussed members. In steel construction, trusses are used either for long spans or as open-web joists. In aluminum, the use of trussed members for intermediate spans both for girders and joists should be considered together with the detail solutions sug-

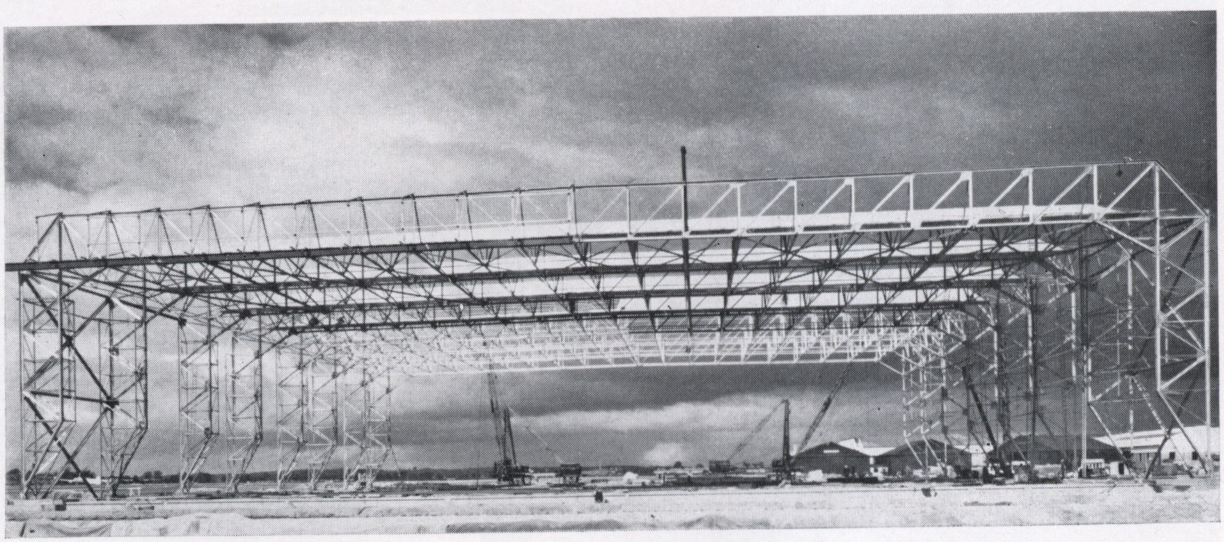


Figure 6-9: De Haviland Hanger, Hatfield, England.

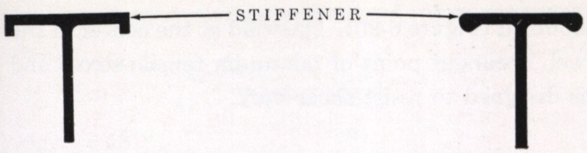


Figure 6-10

Figure 6-11

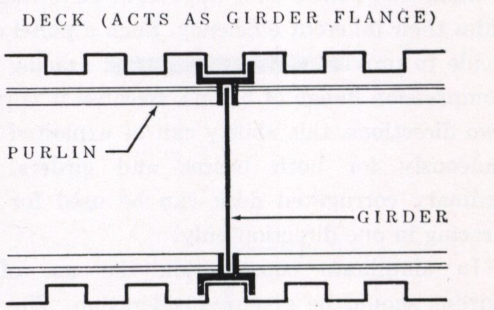


Figure 6-12

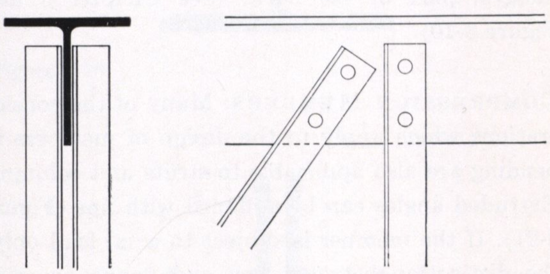


Figure 6-13

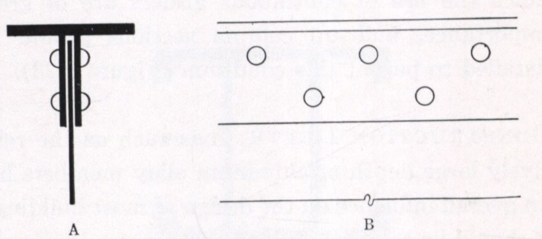


Figure 6-14

gested for the forming of the web-to-flange connections.

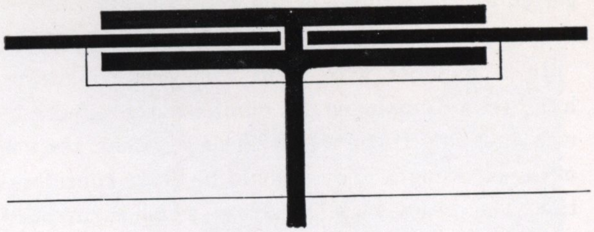
In a member with solid web, various means have to be employed to minimize the effects of web buckling. If the web is shear resistant, the use of lower strength alloys should be given consideration. The critical buckling stress (which is governed by the modulus of elasticity) is substantially the same for the lower strength (and usually cheaper) alloy as it is for the high strength alloys. Removing the ineffective portions of the web leads essentially to the trussed solution, but solid webs can be lightened by cutting out these sections (Figure 6-17). Such details can often be justified because of the high scrap value of aluminum and, therefore, the waste due to cutting out portions of the web is less than it would be with other materials.

In simply supported members, the maximum bending occurs at the section of minimum or zero shear, while the maximum shear is at the section where bending stresses are small. Wedge-shaped members therefore retain their bending efficiency, while buckling is minimized due to the reduced height at the supports (Figure 6-18). While this solution will be useful in reducing the effects of the web instability, the reduced moment of inertia at the area of maximum shear will lead to an increased number of rivets at the flange-web connection.

Web buckling is usually controlled by the use of horizontal and vertical stiffeners. The fabrication cost can be reduced for such members if the web is extruded with integral stiffeners or if the section near the flanges is made of heavier material to reduce the unsupported height of the web (Figure 6-19).

Minimum web thickness can be achieved if the web is allowed to buckle and is utilized to resist the diagonal component of the shear in tension only. This leads to the use of tension field girders, which allow full utilization of materials but at an added cost of fabrication. (See Design Example No. 1).

Since extrusion dies limit the maximum depth of members which can be obtained in a single piece, most deep aluminum members are built up of individual elements. By the use of automatic welding the depth of an extruded member can easily be



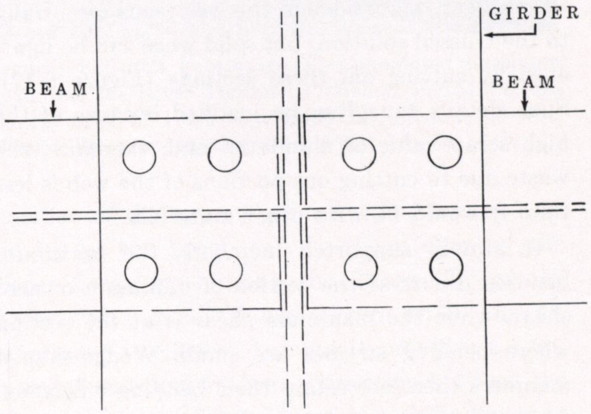


Figure 6-15

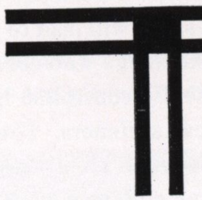


Figure 6-16

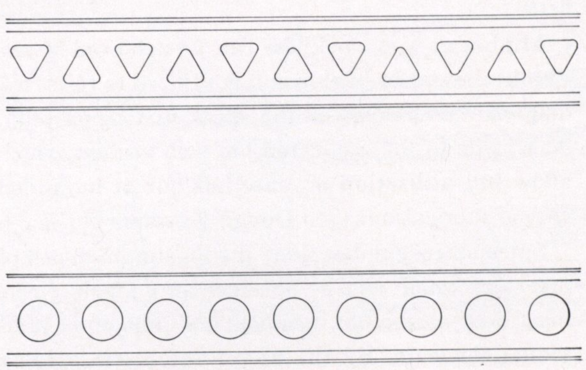


Figure 6-17

doubled (Figure 6-20). The weld at the center of the web occurs at point of minimum tensile stress and is designed to resist shear only.

Deck Structures, especially in multi-story buildings, represent a significant portion of the total dead load of the active structural members. The design of aluminum decks presents problems similar to those of other members in bending. Inasmuch as the deck is usually manufactured of light-gauge material, the elastic stability of its elements governs. The most efficient solution of this problem employs sandwich construction, discussed in detail later in this chapter.

Sandwich panels offer important advantages besides their inherent efficiency. Such a panel can be made to provide continuous lateral bracing of the compression flange of beams. Because it is rigid in two directions, this ability can be exploited simultaneously for both beams and girders, while ordinary corrugated deck can be used for flange bracing in one direction only.

In aluminum construction the use of subpurlins should be given consideration. The extrusion process permits the fabrication of deck members in which the subpurlins or stiffeners are an integral part of the deck. (See Chapter 3 and Figure 3-10).

Compression Members: Many of the considerations which apply to the design of members in bending are also applicable to struts and columns. Extruded angles can be stiffened with lips (Figure 6-21). If the member is subject to axial load only, the distinction between web and flange becomes unimportant and various types of extruded or built-up box sections are favorable (Figure 6-22). Since the use of continuous girders are of great importance, built-up column sections should be detailed to permit this condition (Figure 6-23).

Construction Depth: Inasmuch as the relatively large depth of aluminum alloy members has an overall influence on the design of most buildings, it should be considered at an early stage. In a number of instances the additional depth need not be a

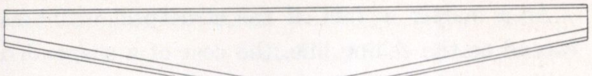


Figure 6-18

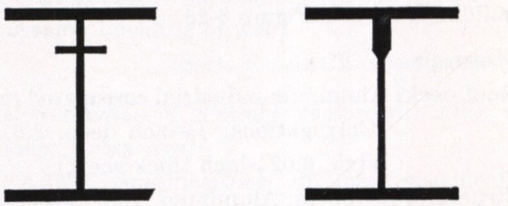


Figure 6-19

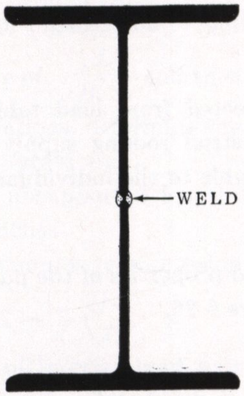


Figure 6-20

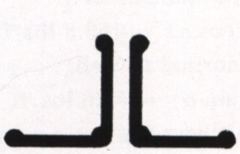


Figure 6-21

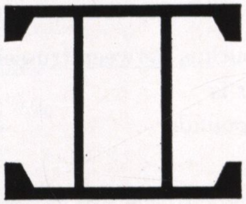


Figure 6-22

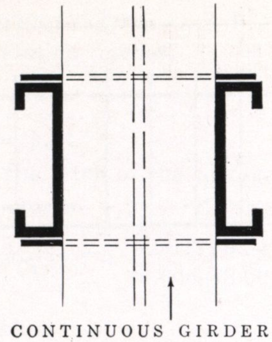


Figure 6-23

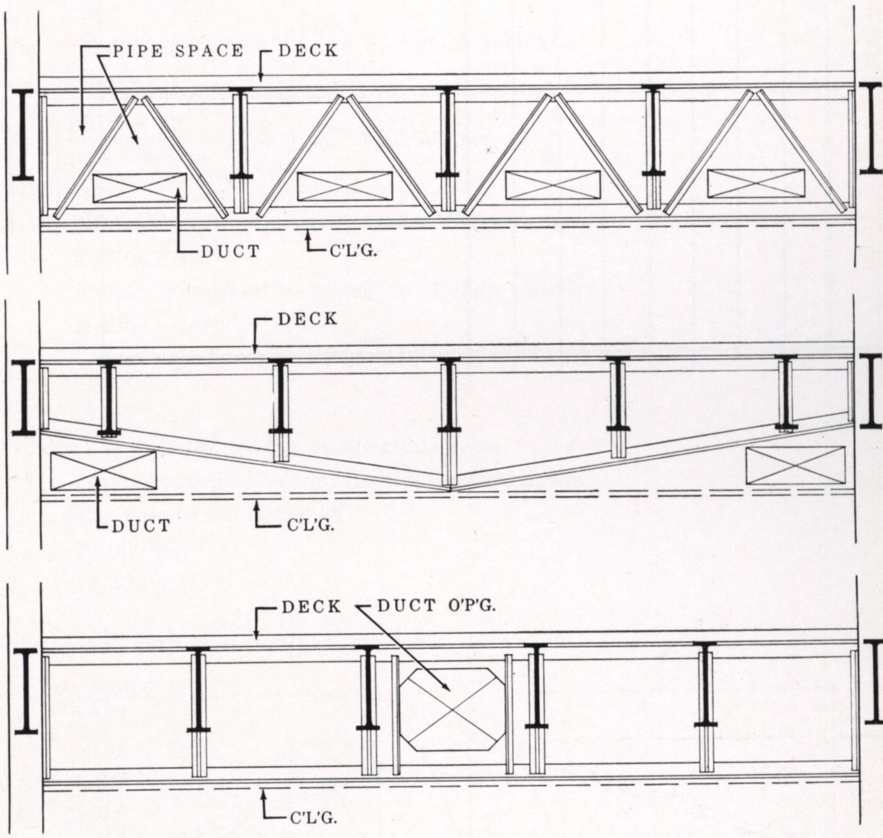


Figure 6-24

drawback. As a matter of fact, in some cases it can be turned into an advantage. In contemporary construction, increasing space is required to accommodate pipes and ducts for heating, air conditioning and ventilating purposes. These conduits are usually accommodated below the structural members. If they are incorporated within the structure, *additional structural depth* is obtained without increasing the total construction depth.

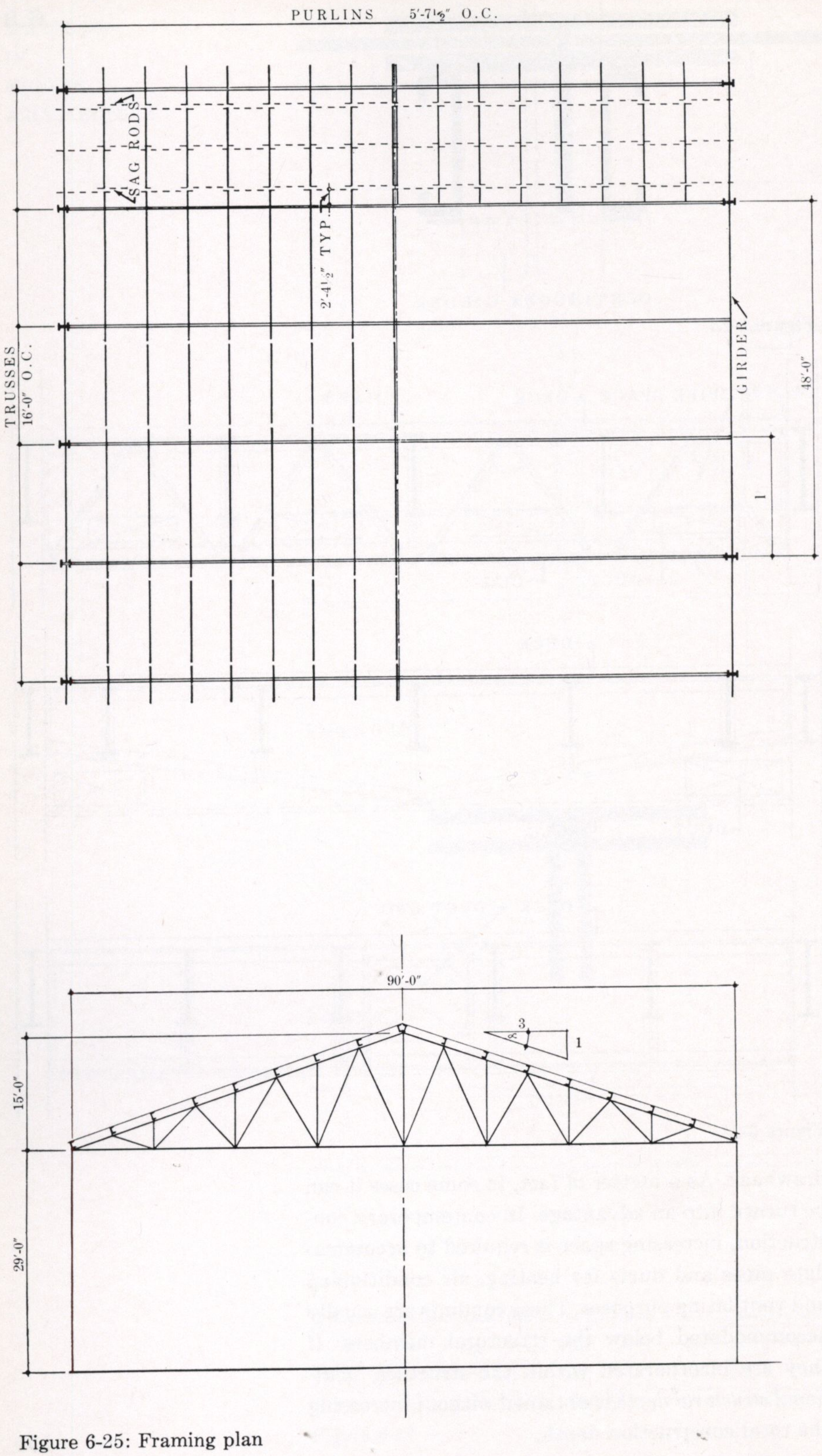


Figure 6-25: Framing plan

As a matter of fact, if the structural members extend to the ceiling line, the cost of a suspended ceiling could in some instances be reduced. Various details are suggested in Figure 6-24.

6.3 DESIGN EXAMPLE NO. 1

Determine structural members for typical bay of building shown in Figure 6-25.

Materials

Roof deck: Aluminum industrial corrugated roofing (Corrugations: ⅞-inch deep, 2.67-inch pitch, 0.024-inch thick sheet)

Structural members: Aluminum Alloy 2014-T6

Loads

Roof live load:	30.00 psf
Deck dead load:	0.42 psf
Total loading:	30.42 psf

Roof Deck

Roof deck selected from load tables. The fabricators of industrial roofing supply the allowable load table suitable to the individual products.

Purlins

Dimensions and properties of the purlin section are shown in Figure 6-26.

Loading

Purlin spacing = 5′7½″ o.c.

Total vertical loading on purlin:

$$w_v - (30.42)\,(5.62) + 1.50 = 172.5 \text{ lbs/ft}$$

Purlin loading in plane of web:

$$w_w = 172.5\,(\cos\alpha) = 163.5 \text{ lbs/ft}$$

Purlin loading normal to web:

$$w_n = 172.5\,(\sin\alpha) = 54.6 \text{ lbs/ft}$$

This structure utilizes the hung span type of purlin framing wherein for all bays (except the end bays) the positive and negative moments are:

$$\pm M_{max} = \frac{W_w L^2}{16} = 2615 \text{ foot-pounds}$$

where

L = Span of purlins between trusses (feet)

The total shear is

$$V_w = 1310 \text{ pounds}$$

Design

In accordance with the ASCE Specifications, the purlin must be checked for the following:

(a) Compressive stress in flange (gross section) (Sect. C—ASCE Specifications)

(b) Local buckling of compression flange (Sect. D—ASCE Specifications)

(c) Shear stress (critical stress for shear buckling) (Sect. E—ASCE Specifications)

(d) Longitudinal compressive stress web (local compression buckling of web) (Sect. F—ASCE Specifications)

(a) *Determination of allowable compressive stress in flange (gross area).*

The ASCE Specifications do not specifically cover light-gauge shapes but it is proposed that the graphs of Section C be applied. The unsupported width of compression flange for light-gauge shapes is determined in accordance with NACA procedure and is shown in Figure 6-26.

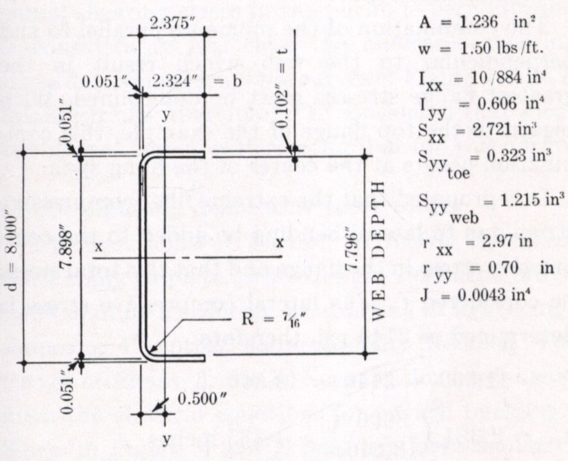
Compute value of $\frac{L}{\sqrt{B/S_c}}$ and then from Figure 3, ASCE Specifications, determine the allowable compressive stress (gross area).

L = laterally unsupported length of compression flange (inches)

S_c = section modulus (compression side) (inches³)

$$B = I_1 d \sqrt{11.7 + \frac{J}{I_1}\left(\frac{L}{d}\right)^2}$$

I_1 = moment of inertia about axis parallel to the web (inches⁴)



PURLIN FABRICATED FROM 0.102″ SHEET

Figure 6-26: Dimensions and properties of purlins.

J = torsion factor (inches⁴)

d = depth of section (inches)

—*Top flange*

$L = 2(2.67'') = 5.34''$

where 2.67″ is the pitch of the corrugations in the roof deck. Therefore:

$$B = 0.606 \times 8.00 \sqrt{11.7 + \frac{0.0043}{0.606}\left(\frac{5.34}{8.00}\right)^2} = 16.6$$

$$\frac{L}{\sqrt{B/S_c}} = \frac{5.34}{\sqrt{\frac{16.6}{2.721}}} = 2.16$$

f_B = 22,000 psi (from Figure 3, ASCE Specifications)

$$f_c = \frac{2615 \times 12}{2.721} = 11{,}500 \text{ psi} < 22{,}000 \text{ psi}$$

where

f_B = allowable compressive stress in flange (gross section) (psi)

f_c = actual compressive stress in flange (gross section) (psi)

—*Bottom flange*

$L = 28\frac{1}{2}''$

where 28½″ is the length of the cantilever.

In a manner similar to that for the top flange, the following values are obtained:

f_B = 21,000 psi

f_c = 11,500 psi

(b) *Local buckling of compression flange*

—*Top flange*

$$\frac{b}{t} = \frac{2.324}{0.102} = 22.8$$

$$\frac{L}{b} = \frac{5.34}{2.324} = 2.29$$

f_c = 11,500 psi

where

b = unsupported width of compression flange (inches)

t = thickness of compression flange (inches)

The limiting or critical value of b/t corresponding to the stress in the gross area is determined from Figure 5 of the ASCE Specifications.

When $(b/t)_{\text{critical}} > (b/t)_{\text{actual}}$, local buckling is not a limiting condition and the full gross area of the flange may be used.

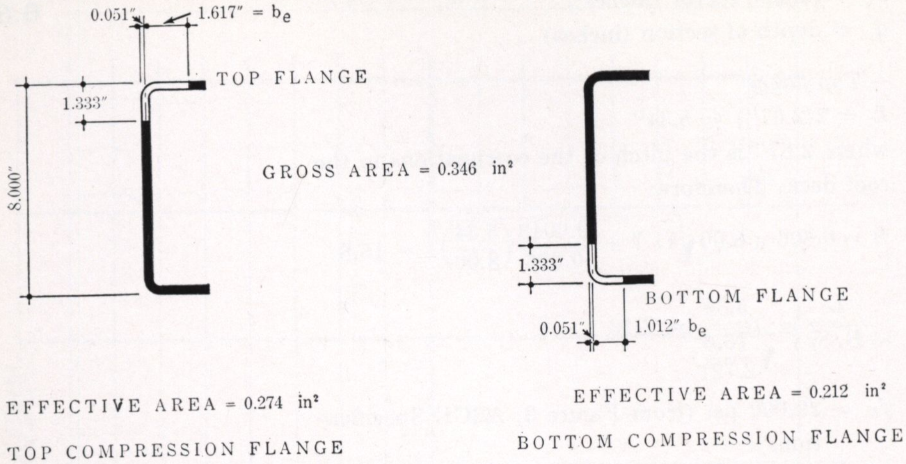


Figure 6-27: Areas of compression flanges.

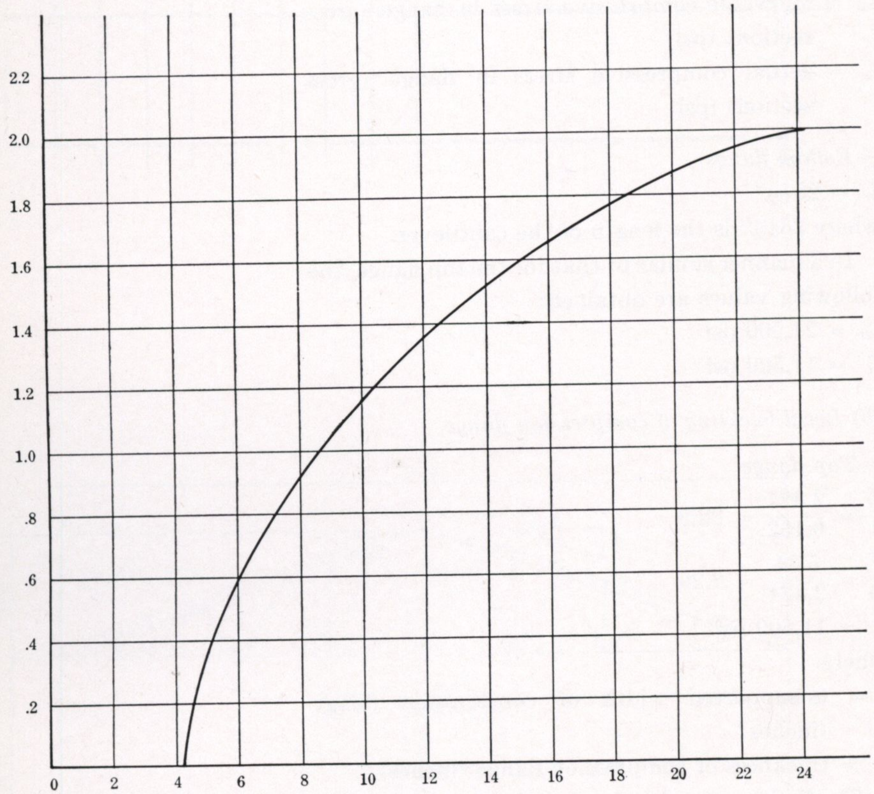


Figure 6-28

When $(b/t)_{\text{critical}} < (b/t)_{\text{actual}}$, then the effective width of the compression flange must be determined. The effective width is calculated from the equation

$b_e = b\, f_l/f_c$

where

b_e = that part of the unsupported width considered effective (inches)

f_l = stress found from Figure 5 of the ASCE Specifications, corresponding to $(b/t)_{\text{actual}}$ (psi)

f_l = 8000 psi and from the equation above:

$$b_e = 2.324 \left(\frac{8000}{11{,}500}\right) = 1.617 \text{ inches}$$

The compressive stress (f_{ce}) on the effective area is determined from the following equation:

$$f_{ce} = f_c \frac{\text{gross flange area}}{\text{effective flange area}}.$$

Included in the flange areas is the outermost one-sixth of the overall depth of the section. (Figure 6-27 shows the effective compression flanges); therefore

$$f_{ce} = 11{,}500 \left(\frac{0.346}{0.274}\right) = 14{,}500 \text{ psi} < 22{,}000 \text{ psi}$$

For a flat roof structure, this is as far as it would be necessary to go in checking the stresses in the compression flanges. However, in this particular case, it is necessary to check for the stresses due to the component of roof loading which is perpendicular to the web of the purlin. These lateral stresses are easily determined and will not be treated in detail here.

The combination of the moments parallel to and perpendicular to the web which result in the greatest flange stresses must be determined. With regard to the top flange of the example, this combination occurs at the center of the hung span.

It is proposed that the extreme fiber compressive stress due to lateral bending be added to the compressive stress in the flange and that this total stress be considered f_c. The lateral compressive stress is determined as 2140 psi, therefore

$$f_c = 11{,}500 + 2140 = 13{,}640$$

$$b_e = 2.324 \left(\frac{8000}{13{,}640}\right) = 1.365 \text{ inches}$$

$$f_{ce} = 13{,}640 \left(\frac{0.346}{0.248}\right) = 19{,}050 \text{ psi} < 22{,}000 \text{ psi}$$

This procedure is conservative, since the allowable critical buckling stress for a plate subjected to bending is much greater than that for a plate subjected to a uniform axial compressive stress.

—Bottom flange

These stress computations are similar to those for the top flange, and the total extreme fiber compressive stress in the flange on the effective area is

Total $f_{ce} = 19{,}650 \text{ psi} < 21{,}200 \text{ psi}$

(*c*) *Check for shear buckling*

$$\frac{b_w}{a} = \frac{7.796}{16 \times 12} = 0.04$$

$$\frac{b_w}{t} = \frac{7.796}{0.102} = 76.5$$

where

b_w = depth of purlin web (inches)

a = purlin span (inches)

From Figure 7, ASCE Specifications and values of $\frac{b_w}{a}$ and $\frac{b_w}{t}$ determine allowable shear stress (v allowable:

$v_{\text{allowable}} = 6000$ psi

The actual shear stress (v_{actual}) = 1645 psi < 6000 psi.

The graph of Section E, ASCE Specifications is based upon a condition of partial restraint at the edges of the panel or web. The light-gauge shape cannot be considered as meeting this condition; all edges are considered as simply supported. The actual shearing stress in the purlin is very low and is considerably less than the allowable shearing stress determined from the curves of Figure 7, ASCE Specifications; therefore, it is considered that shear buckling is not a critical condition for the purlin.

(*d*) *Longitudinal compressive stress in web*

The provisions of Section F, ASCE Specifications apply to plate girder design. Pertinent provisions shall be considered as applying to light-gauge shapes or any other shape specially designed. The curves of Figure 8, ASCE Specifications, are based upon the classical equations for critical buckling.* Since (in Figure 8, ASCE Specifications) the curve of critical stresses for the condition of a girder with no horizontal stiffener is based upon a condition of partial restraint at the edges, it will be necessary, for the light-gauge shape, to enter into the equation

$$\text{Allowable stress} = k\,\frac{\pi^2 E}{12(1-\mu^2)}\left(\frac{t}{b_w}\right)^2\left(\frac{1}{F.S.}\right)$$

where

k = instability constant

E = modulus of elasticity of material (psi)

μ = Poisson's ratio

$F.S.$ = factor of safety (use 1.5, as in ASCE Specifications)

t = thickness of web (inches)

b_w = depth of web (inches)

The instability constant (k) is a function of the ratio of the span to the depth of the web and of α, where α is a function of the combination of bending and axial compression stresses. The lateral compressive stress in the web is considered an axial stress since it is uniform over the entire depth of the web. Figure 6-28 is a graph of "K" values plotted against α.** To determine α use the following equation:

$$\alpha = \frac{2}{1 + \dfrac{\text{axial compression stress}}{\text{compressive stress due to bending}}}$$

therefore

$$\alpha = \frac{2}{1 + \dfrac{2140}{\left(\dfrac{11{,}500 \times 7.796}{13{,}640 \times 8.00}\right) 19{,}050}} = 1.76$$

k = 17.3

Allowable stress =

$$15.7\left[\frac{\pi^2(10.6 \times 10^6)}{12(1 - [1/3]^2)}\right]\left(\frac{0.102}{7.796}\right)^2\left(\frac{1}{1.5}\right) = 17{,}500 \text{ psi}$$

Actual maximum stress in the web is

$15{,}620 + 2140 = 17{,}760 \text{ psi} < 19{,}400 \text{ psi}$

Sag Rods

Rods are ⅜-inch diameter with upset ends. Sag rods are determined from the lateral component of the purlin loading.

* THEORY OF ELASTIC STABILITY, S. Timoshenko. p. 355.

** Timoshenko op. cit. and BUCKLING STRENGTH OF METAL STRUCTURES, Hans Bleich, p. 401.

Roof Truss

The roof truss is illustrated in Figure 6-29. Member lengths, stresses and sections are listed in Table 6-1.

The designs for one compression member and one tension member will be shown in detail to illustrate the procedure.

Truss member L_o-U_1 consists of two angles that are $3\frac{1}{2}'' \times 2\frac{1}{2}'' \times \frac{3}{8}''$ as shown in Figure 6-30.

$P = -67.0^K$

$l = 71.12$ inches

$(l/r)_{\text{allowable}} \leq 120$

$r = 1.07$ inches

$A = 4.20$ inches^2

$(l/r)_{\text{actual}} = 66.5$

where

P = axial load on member (kips)

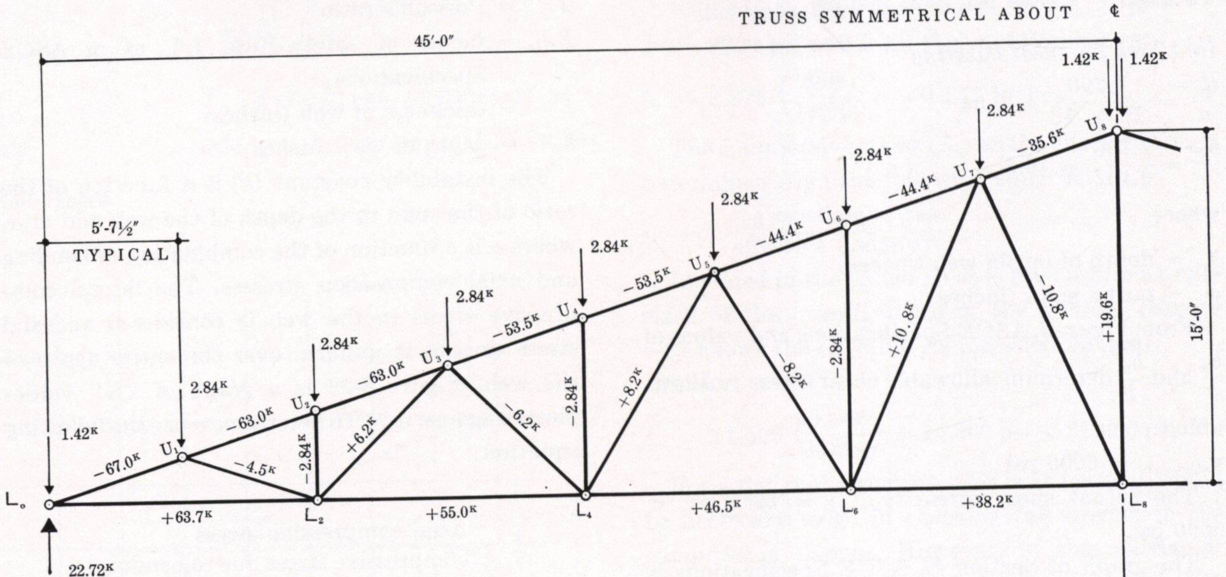


Figure 6-29: Roof truss.

TABLE 6-1: TRUSS MEMBERS

MEMBER	LENGTH (FT)	STRESS (KIPS)	SECTION
L_0-U_3	17.77	−67.0	2 ⅃L 3½ x 2½ x ⅜
U_3-U_5	11.85	−53.5	2 ⅃L 3½ x 2½ x 5⁄16
U_5-U_8	17.77	−44.4	2 ⅃L 3½ x 2½ x ¼
U_1-L_2	5.93	− 4.5	1 L 3 x 3 x 3⁄16
U_3-L_4	7.96	− 6.2	2 ⅃L 3 x 2 x 3⁄16
U_5-L_6	10.92	− 8.2	2 ⅃L 3½ x 3 x 3⁄16
U_7-L_8	14.30	−10.8	2 ⅃L 6 x 4 x 3⁄16
U_2-L_2	3.75	− 2.84	1 L 2 x 2 x ⅛
U_4-L_4	7.50	− 2.84	2 ⅃L 2½ x 2 x ⅛
U_6-L_6	11.25	− 2.84	2 ⅃L 3½ x 3 x 3⁄16
U_8-L_8	15.00	+19.6	2 ⅃L 4 x 3 x ¼
L_2-U_3	7.96	+ 6.2	2 ⅃L 2 x 1¼ x ⅛
L_4-U_5	10.92	+ 8.2	2 ⅃L 3 x 2½ x ⅛
L_6-U_7	14.30	+10.8	2 ⅃L 4 x 3 x ¼
L_0-L_4	22.50	+63.7	2 ⅃L 3 x 2 x ⅜
L_4-L_8	22.50	+46.5	2 ⅃L 3 x 2½ x ¼

l = length of member (inches)
r = least radius of gyration of member (inches)
A = area of member (inches²)

The section will be checked for the following:

(a) Allowable column compressive stress (gross section) (Sect. B, ASCE Specifications)

(b) Local buckling. (Sect. D, ASCE Specifications)

(a) *The allowable compressive* unit stress (f_{cc}) in gross section is determined from Figure 2, ASCE Specifications.

f_{cc} = 16.2 ksi (for condition of partial restraint at ends)

$$f_c = P/A = \frac{67.0}{4.20} = 15.95 \text{ ksi} < 16.2 \text{ ksi}$$

(b) *Local buckling*

Check for local buckling of outstanding leg. The legs back to back will be stitch riveted together; therefore, they need not be considered (See Section 4.1).

$l/b = 33.5$
f_c = 15.95 ksi ≅ 16.0 ksi
$(b/t)_{\text{critical}}$ = 12.3 (from Figure 5, ASCE Specifications)
$(b/t)_{\text{actual}}$ = 5.67 < 12.3; therefore local buckling is not a critical condition.

When $(b/t)_{\text{actual}} > (b/t)_{\text{critical}}$, the effective width of the outstanding leg must be obtained from the equation $b_e = b\left(\frac{f_t}{f_c}\right)$, and the compressive stress is then computed on the effective area. Make member L_o-U_3 continuous and of same section as L_o-U_1.

Truss member L_o-L_2 consists of two angles
3″ × 3″ × 5⁄16″.

$P = +63.7^K$
l = 135 inches

$$(l/r)_{\text{allowable}} \leqq 150 + \frac{f_t}{100} \text{ (Sect. H, ASCE Specifications)}$$

r = 0.92 inch
A = 3.54 inches²
$(l/r)_{\text{actual}}$ = 147

where

f_t = the lowest net tensile stress to which the member will be subjected in actual service (psi).

The member need only be checked for allowable (l/r) and stress on net section.

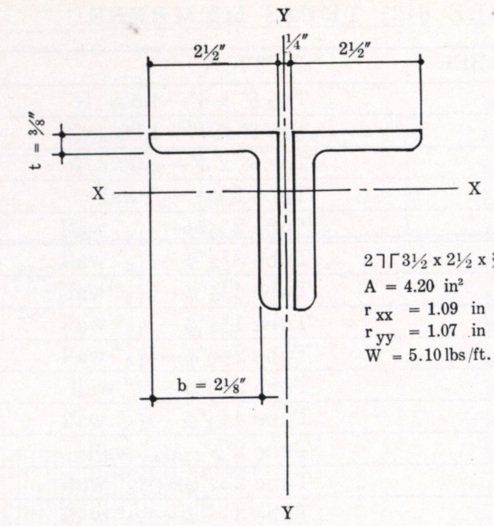


Figure 6-30: Section member L_0-U_1

Dead load is approximately 10 percent of the total load, therefore

$$f_t = \frac{6.37 \times 1000}{3.54} = 1800 \text{ psi}$$

$$(l/r)_{\text{allowable}} = 150 + \frac{1800}{100} = 168 > 147$$

Assuming ⅞-inch diameter rivets:
Net area = 3.54 in.² − 0.56 in.² = 2.98 in.²
Therefore, the net tensile unit stress is

$$f_t = \frac{63.7}{2.98} = 21{,}400 \text{ psi} < 22{,}000 \text{ psi}$$

Make member L_o-L_4 continuous and of same section as L_o-L_2.

The design of a typical truss connection is shown in Section 4.11.

The total weight of one complete truss (including allowance for gussets and rivets) is 1450 pounds or 16.1 pounds per foot.

It is possible to design this truss using thin-walled tubes as web members. The chord members are changed to Tees to allow for connecting the tubes. Design for one compression member and one tension member are shown below:

Alternate Roof Truss

Table 6-2 lists the sections required.

Truss member U_1-L_2 consists of a 2-inch diameter tube with ⅛-inch wall.

TABLE 6-2: TRUSS MEMBERS

MEMBER	SECTION
L_0-U_3	Tee 6″ x 4″—4.93#/ft
U_3-U_5	Tee 6″ x 4″—4.00 #/ft
U_5-U_8	Tee 6″ x 4″—4.00 #/ft
U_1-L_2	Tube 2″φ—⅛″ wall
U_3-L_4	Tube 2¾″φ—3⁄16″ wall
U_5-L_6	Tube 3¼″φ—3⁄16″ wall
U_7-L_8	Tube 4¼″φ—3⁄16″ wall
U_2-L_2	Tube 1¾″φ—1⁄16″ wall
U_4-L_4	Tube 2½″φ—1⁄16″ wall
U_6-L_6	Tube 3½″φ—⅛″ wall
U_8-L_8	Tube 4½″φ—3⁄16″ wall
L_2-U_3	Tube 2″φ—3⁄16″ wall
L_4-U_5	Tube 2¾″φ—3⁄16″ wall
L_6-U_7	Tube 3½″φ—3⁄16″ wall
L_0-L_4	Tee 6 x 4—4.00 #/ft
L_4-L_8	Tee 6 x 4—4.00 #/ft

$P = -4.54^{K}$
$l = 71.12$ inches
$(l/r)_{\text{allowable}} = 120$
$r = 0.664$ inch
$A = 0.736$ inches²
$(l/r)_{\text{actual}} = 107$

The section will be checked for the following:

(a) Allowable column compressive stress
(b) Local buckling

(a) *Allowable column compressive unit stress* (f_{cc}) is determined from Figure 2, ASCE Specifications.

$f_{cc} = 10.8$ ksi (partial restraint at ends)

$$f_c = \frac{4.5}{0.736} = 6.1 \text{ ksi} < 6.5 \text{ ksi}$$

(b) *Local buckling*
The ASCE Specifications do not cover the condition of local buckling in tubes. Therefore, the critical buckling stress will be determined by using the following equation*

$$\sigma_a = \frac{Et}{a\sqrt{3(1-\mu^2)}}$$

where
t = wall thickness of tube
a = radius of the tube to center of wall
A factor of safety of 2.5 will be used.

* Timoshenko, op. cit. p. 457.

Allowable stress = 346,000 psi
Local buckling is not a consideration.

Truss member L_2-U_3 consists of a 2-inch diameter tube with 3⁄16-inch wall.

$P = +6.24^{K}$
$l = 95.5$ inches

$$(l/r)_{\text{allowable}} \leqq 150 + \frac{f_t}{100}$$

$r = 0.644$ inch
$A = 1.068$ inch²
$(l/r)_{\text{actual}} = 148.5$

The section is checked for allowable (l/r) and stress on net section as follows:

$(l/r)_{allowable} = 156.5 > 148.5$
Assuming ⅝-inch diameter rivets
Net area = 1.068 − 0.240 = 0.828 inches²

$$f_t = \frac{6.24}{0.828} = 7.54 \text{ ksi} < 22.0 \text{ ksi}$$

A tube of 2-inch diameter and ⅛-inch wall would satisfy the design conditions but would not allow for sufficient riveting.

The total weight of one complete truss is 1183 pounds or 13.2 pounds per foot.

BUILT-UP GIRDER: (Shear resistant web) Figure 6-31 shows loading on girder, moment diagram and shear diagram. Figure 6-32 shows section and properties.

In accordance with the ASCE Specifications, the girder will be designed by the Moment of Inertia method and the following conditions computed and checked:

(a) Allowable compressive stress in flange (gross section).
(b) Local buckling of compression flange.
(c) Spacing of intermediate vertical stiffeners. (Sect. F, ASCE Specifications)
(d) Vertical stiffener at point of load. (Sect. F, ASCE Specifications)
(e) Vertical bearing stiffener at supports. (Sect. F, ASCE Specifications)
(f) Longitudinal compression stress in web. (Sect. F, ASCE Specifications)

(a) *Allowable compressive stress in flange (gross section)*

$$B = I_1 d \sqrt{11.7 + \frac{J}{I_1}\left(\frac{L}{d}\right)^2} =$$

$$110.75 \times 40.00 \sqrt{11.7 + \frac{0.811}{110.75}\left(\frac{192}{40.00}\right)^2} = 15{,}250$$

$$\frac{L}{\sqrt{\frac{B}{s_c}}} = \frac{192}{\sqrt{\frac{15250}{332}}} = 28.3$$

$f_B = 13{,}500$ psi (from Figure 3, ASCE Specifications)

$$f_c = \frac{371 \times 12{,}000}{332} = 13{,}400 \text{ psi} < 13{,}500 \text{ psi}$$

$$f_t = \frac{371 \times 12{,}000}{272} = 16{,}350 \text{ psi} < 22{,}000 \text{ psi}$$

(b) *Check for local buckling of compression flange*

$$\frac{L}{b} = \frac{192}{5\frac{9}{16}} = 34.5$$

$$\frac{b}{t} = \frac{5\frac{9}{16}}{\frac{7}{16}} = 12.7$$

$(b/t)_{critical} = 14.0$ (from Figure 5, ASCE Specifications)

14.0 > 12.7 therefore, local buckling is not a critical condition.

(c) *Spacing of vertical stiffeners* (1 angle 2″ × 2″ × ⅛″)

$$\frac{h}{t_w} = \frac{33.0}{0.188} = 176$$

$$v = \frac{23{,}390}{7.40} = 3160 \text{ psi}$$

where

h = clear height of web between flanges (inches)

t_w = thickness of web (inches)

v = shear in web (psi)

From Figure 9, ASCE Specifications, determine

$$\frac{s}{h} = 0.7$$

$$\frac{I_s}{t^4} = 175$$

where

s = required spacing between intermediate vertical stiffeners (inches)

I_s = moment of inertia of stiffener, required to resist shear buckling (inches⁴)

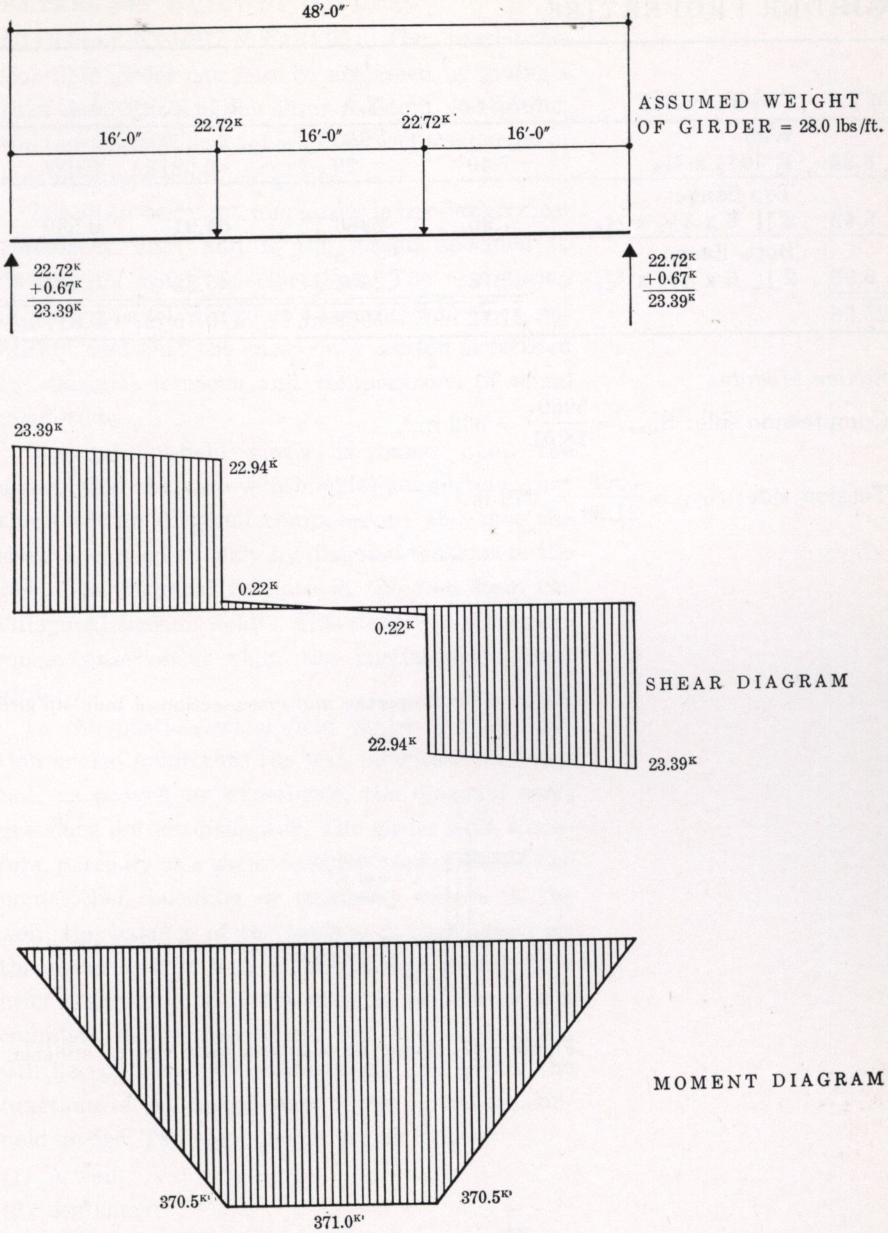


Figure 6-31: Loading, shear and moment diagrams of built-up girder.

therefore

$S = 0.7\,(33.0) = 23.1$ inches

$I_s = 175\,(\frac{3}{16})^4 = 0.216$ inches^4

Figure 6-33 shows properties of vertical stiffeners.

Stiffener satisfactory since

0.32 inches^4 > 0.216 inches^4

(d) *Vertical stiffener at point of load* (2 angles 4″ × 3″ × ½″)

GIRDER PROPERTIES

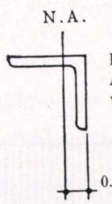
WT.	COMPONENT	AREA	I_{xx} @ N.A.	$I_{yy}=I_1$	J
8.96	Web R $39\frac{1}{2} \times \frac{3}{16}$	7.40	963 29	0.0218	0.087
9.62	Top flange 2⅂⎾ $6 \times 3\frac{1}{2} \times \frac{7}{16}$	7.96	7 2360	64.91	0.530
6.98	Bott. flange 2⅃L $6 \times 3\frac{1}{2} \times \frac{5}{16}$	5.76	5 2605	45.82	0.194
25.56		21.12 in.^{2}	5969 in.^{4}	110.75 in.^{4}	0.811 in.^{4}

Section Modulus

Compression side: $S_{Cxx} = \dfrac{5969}{18.01} = 332 \text{ in.}^3$

Tension side: $S_{txx} = \dfrac{5969}{21.99} = 272 \text{ in.}^3$

Figure 6-32: Properties and cross-section of built-up girder.

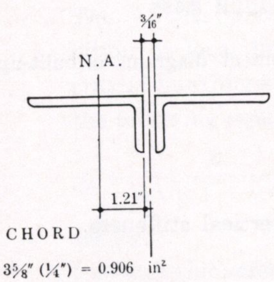


$I_{NA} = 0.18$ in^4
$A = 0.49$ in^2
$w = 0.59$ lbs./ft.

$I_{\text{back of angle}} = 0.18 + 0.49\,(0.53)^2 = 0.32$ in^4

Figure 6-33: Properties of intermediate vertical stiffener.

ONE ANGLE
$I_{NA} = 2.68$ in^4
$A = 1.69$ in^2
$w = 2.05$ lbs./ft.



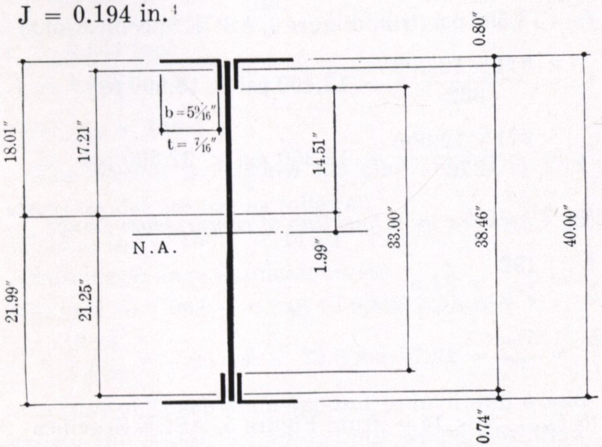
$I_{\text{¢}} = 2.68+1.69\,(1.30)^2 = 2.68+2.86 = 5.54$ in^4
TOTAL $I_{\text{¢}} = 2(5.54) = 11.08$ in^4
TOTAL $A_B = 2(0.906) = 1.812$ in^2

BEARING AREA
FILLET RADIUS TOP CHORD
ANGLE = 3/8"
$\therefore 4'' - \frac{3}{8}'' = 3\frac{5}{8}''$ AND $A_B = 3\frac{5}{8}''\,(\frac{1}{4}'') = 0.906$ in^2

Figure 6-34: Properties of bearing stiffener.

2⅂⎾ $6 \times 3\frac{1}{2} \times \frac{7}{16}$
$A = 7.96 \text{ in.}^2$ $\qquad I_{xx} = 7.32 \text{ in.}^4$
$w = 9.62$ lbs/ft $\qquad I_{yy} = 64.91 \text{ in.}^4$
$J = 0.930 \text{ in.}^4$

2⅃L $6 \times 3\frac{1}{2} \times \frac{5}{16}$
$A = 5.76 \text{ in.}^2$ $\qquad I_{xx} = 5.40 \text{ in.}^4$
$w = 6.98$ lbs/ft $\qquad I_{yy} = 45.82 \text{ in.}^4$
$J = 0.194 \text{ in.}^4$



$$I = I_s + \frac{Ph^2}{74{,}000{,}000}$$

where

I = moment of inertia of stiffener at point of bearing (inches^4)

P = local load concentration on stiffener (pounds)

therefore

$$I = 0.216 + \frac{22{,}720\ (33.0)^2}{74{,}000{,}000} = 0.216 + 0.334 = 0.550 \text{ inch}^4$$

Bearing Area (A_B) required

$$A_B = \frac{\text{P}}{\text{allowable bearing stress}} = \frac{22{,}720}{36{,}000} = 0.630 \text{ inch}^2$$

Figure 6-34 shows properties of vertical stiffener.

Stiffener satisfactory since
11.08 inch^4 > 0.550 inch^4
1.812 inch^2 > 0.630 inch^2

(e) *Vertical bearing stiffener at supports* (2 angles $4'' \times 3'' \times \frac{1}{4}''$)

$$I = I_s + \frac{Ph^2}{74{,}000{,}000}$$

$$I = 0.216 + \frac{23{,}390\,(33.0)^2}{72{,}000{,}000} = 0.216 + 0.343 = 0.559 \text{ inch}^4$$

Bearing area required

$$A_B = \frac{P}{\text{Allowable bearing stress}} = \frac{23390}{36000} =$$
$$0.650 \text{ inch}^2$$

Figure 6-34 shows properties of vertical end stiffener. Stiffener satisfactory, since

$11.08 \text{ inch}^4 > 0.570 \text{ inch}^4$

$1.812 \text{ inch}^2 > 0.650 \text{ inch}^2$

(*f*) *Longitudinal compression stress in web*

$$(f_{CL})_{actual} = \frac{14.88}{18.38}(13{,}050) = 10{,}580 \text{ psi}$$

$$\frac{h}{t} = 176$$

$(f_{CL})_{allowable} = 6500 \text{ psi} < 10{,}580 \text{ psi}$ (From Figure 8, ASCE Specifications. No horizontal stiffener.)

$(f_{CL})_{allowable} = 22{,}000 \text{ psi} > 10{,}580 \text{ psi}$ (From Figure 8, ASCE Specifications. With horizontal stiffener.)

Therefore, a single horizontal stiffener is necessary and the required moment of inertia for the horizontal stiffener is determined from

$$I_h = \frac{(f_{CL})_{actual}}{1000} t_w h^3 \left[\left(16 + 90\frac{A_h}{ht}\right)\left(\frac{s}{h}\right)^2 + 6\right]10^{-7}$$

where

I_h = moment of inertia of the horizontal stiffener (inches^4)

A_h = area of the horizontal stiffener (inches^2)

therefore

$$I_h = 10.8(3/16)(33)^3\left[\left\{16+90\frac{A_h}{33(3/16)}\right\}0.7^2+6\right]10^{-7}$$

$$I_h = 0.1007 + 0.0518\,A_h$$

for a horizontal stiffener consisting of one angle $2'' \times 1\frac{1}{2}'' \times \frac{1}{8}''$; then

$$I_h = 0.1007 + 0.0502\,(0.42) = 0.118 \text{ inch}^4$$

The moment of inertia of the horizontal stiffener about the back of the angle with $1\frac{1}{2}$-inch leg outstanding is 0.134 inch^4, therefore stiffener satisfactory since $0.134 \text{ inch}^4 > 0.118 \text{ inch}^4$

Total weight of the girder (with allowance for riveting) is 1430 pounds or 29.8 pounds per foot.

This girder may also be designed as a partial tension field beam with thin web. The flanges will be extruded sections.

Alternate Built-up Girder (Partial Tension Field): The partial-tension-field girder can best be explained by giving a brief description of the shear-resistant web girder, the tension-field or wagner girder and the partial or incomplete-tension-field girder.

The shear-resistant web girder is the design most commonly used and is the design specified in Section F, ASCE Specifications. The assumption in this type of design is that the web does not buckle, and that the shear on a section is resisted by diagonal tensions and compressions of equal magnitude.

The tension-field girder is based upon the assumption that the web buckles completely, that there are no diagonal compressions and that the shear is carried entirely by diagonal tensions in the web. The diagonal tensions in the web form the "diagonal tension field". This design is somewhat more conservative than the partial-tension-field girder.

In the partial-tension-field girder the assumption is also made that the web buckles completely but, as proved by experience, the diagonal compressions do not disappear. The girder acts, therefore, partially as a shear-resistant web girder to the point when buckling or wrinkling occurs in the web; the balance of the loading is then taken by the girder as if it were a tension-field girder. In a brief description, it is not possible to enter into a complete design procedure, but the explanation will be continued by enumerating and giving the functions of the components of the partial-tension-field girder. The components are as follows:

(1) A web

(2) Stiffeners

  —Intermediate

  —End

(3) Chords

The web function has been adequately described in the introduction to the partial-tension-field girder; therefore, it may merely be said that the web carries the shear by means of an incomplete diagonal tension field.

The functions of the stiffeners are as follows:

—The intermediate stiffener acts to break up

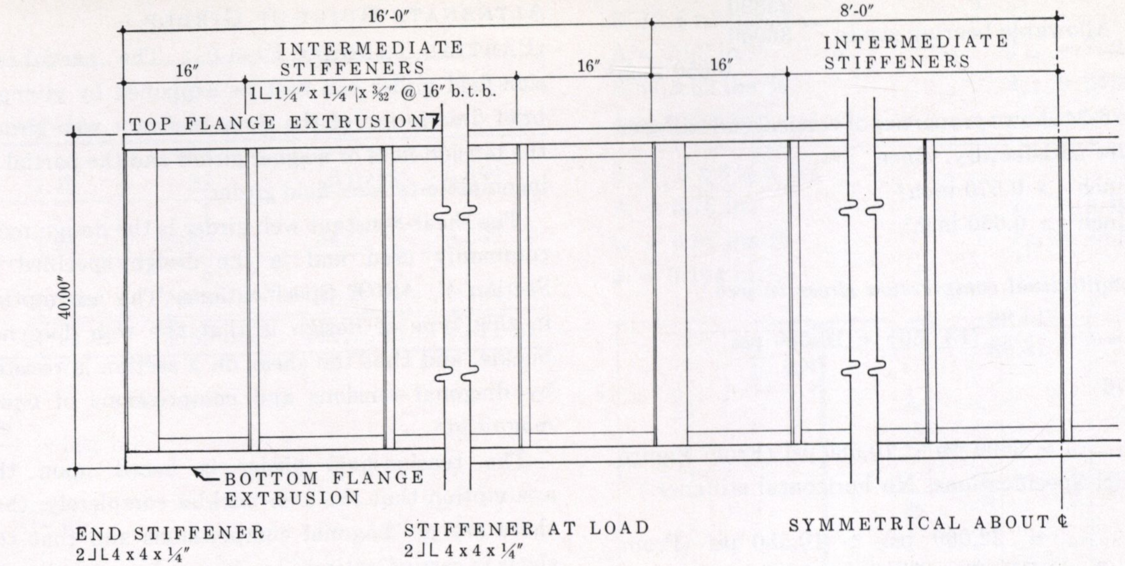
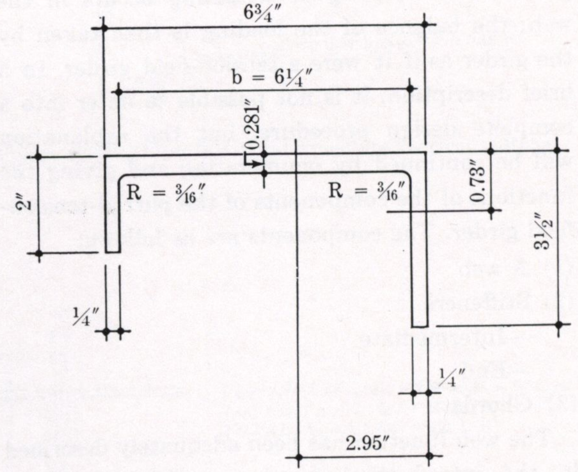
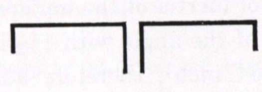


Figure 6-35: Partial-tension-field girder.



A = 3.130 in^2
I_{xx} = 2.630 in^4
I_{yy} = 19.770 in^4
J = 0.075 in^4

TOTAL FLANGE SECTION



A = 6.26 in^2
I_{xx} = 5.236 in^4
I_{yy} = 95.540 in^4
J = 0.150 in^4

Figure 6-36: Properties of flange section.

the deformation patterns in the web into groups of wrinkles. The wrinkles are prevented by the stiffener from passing from one side of the stiffener to the other. The stiffener must also act as a column to resist the difference in vertical components of the diagonal tensions and diagonal compressions in the web.

—The end stiffener serves the same function as the intermediate stiffener with the addition of the requirement that it sustain the concentrated load and also that it resist in bending the lateral component of the diagonal tension field. The end stiffener acts as a beam-column.

The chord must resist stresses due to the following three factors:

—Stresses due to bending moment in girder.

—Stresses due to secondary bending moment in chord as a result of the components of the diagonal tension field acting perpendicular to the chords.

—Axial stresses due to the components of the diagonal tension field acting parallel to the chords.

The partial-tension-field girder as determined in this example is diagrammed in Figure 6-35. Figure 6-36 shows section and properties of the flange member, whereas Figure 6-37 shows section and properties of the girder. The total weight of the partial tension field beam is 1070 pounds or 22.3 pounds per foot. As a further illustration of the design of this particular girder, the allowable stresses and the actual stresses in each component will be given.

(1) Web

Shear stress in web = 8,720 psi
Critical buckling stress = 1,830 psi
Allowable web stress = 14,800 psi

(2) Stiffeners

—Intermediate stiffener
Compressive stress in stiffener = 3,370 psi
Allowable compressive stress to preclude torsional failure = 4,860 psi
Allowable compressive stress to preclude local buckling = 10,000 psi
Allowable column stress = 6,130 psi

—End stiffener
Axial compressive stress in stiffener = 3,110 psi
Compressive stress due to bending = 7,260 psi
Total compressive stress = 10,370 psi
Allowable compressive stress to preclude torsional failure = 12,900 psi
Allowable compressive stress to preclude local buckling = 11,800 psi
Allowable column stress = 11,300 psi

(3) Chords

Top chord only will be considered in illustration.
Compressive stress due to primary bending = 17,550 psi
Compressive stress due to secondary bending in chord = 730 psi
Axial stress due to diagonal tension field = 650 psi
Total compressive stress = 18,930 psi
Allowable compressive stress = 19,200 psi

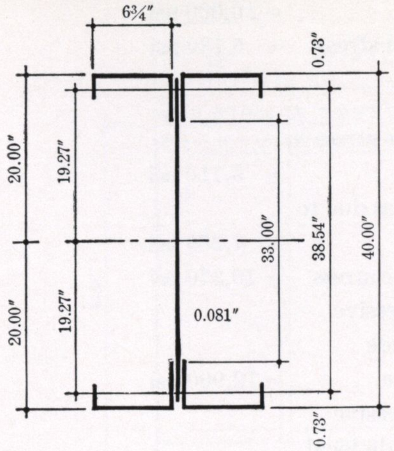
COLUMN: The column at the built-up girder will be investigated. Figure 6-38 shows framing plan and properties of column section.

The column will be checked for the following conditions:

(a) Failure of column by bending in plane of bending forces. (Sect. B, ASCE Specifications.)
(b) Failure of column by buckling normal to plane of bending forces. (Sect. B, ASCE Specifications.)

Loading conditions:
From Girder 23,390 pounds
From truss 22,720 pounds
Total P = 46,110 pounds

Moment due to eccentricity of connection:
$M_x = 22,720\ (4'') = 90,880$ foot-pounds
$l_x = 348$ inches



WT.	COMPONENT	AREA	I_{xx} @ N.A.	$I_{yy} = I_1$	J
3.94	Web 39½ x 0.081	3.20	416	...	0.007
7.70	Top flange Extrusion	6.26	5 2325	95.66	0.150
7.70	Bott. flange Extrusion	6.26	5 2325	95.66	0.150
19.34lbs/ft		15.72 in.²	5076 in.⁴	191.32 in.⁴	0.307 in.⁴

Figure 6-37: Properties of built-up girder (partial tension field).

Section Modulus

$$S = \frac{5076}{20.00} = 253.80 \text{ in.}^3$$

$$l_y = 174 \text{ inches}$$

$$(l/r)_{\text{allowable}} \leqq 120$$

(a) *Check for failure of column by bending in plane of bending forces.*

$$(l/r)_{x\ \text{actual}} = 105$$

$$B = 36.79\ (8.00) \sqrt{11.7 + \left(\frac{0.96}{36.79}\right)\left(\frac{174}{8.00}\right)^2} = 1445$$

$$\frac{L}{\sqrt{B/s_c}} = 25.1$$

f_B = 16,500 psi (from Figure 3, ASCE Specifications)
F_c = 6,800 psi (from Figure 2, ASCE Specifications —Partial restraint at ends)

$$f_c = \frac{46{,}110}{11.01} = 4180 \text{ psi}$$

$$f_b = (f_B - f_c)\left(1 - \frac{f_c}{F_c}\right)$$

$$(f_b)_{\text{actual}} = \frac{90{,}880}{30.23} = 3000 \text{ psi}$$

where

$f_{b\ \text{actual}}$ = extreme fiber stress due to bending

f_b = the maximum allowable bending stress (compression) at or near the center of the unsupported length

f_B = allowable compressive working stress for a member considered as a beam

F_c = allowable working stress for a member considered as an axially loaded column tending to fail in the plane of the bending forces

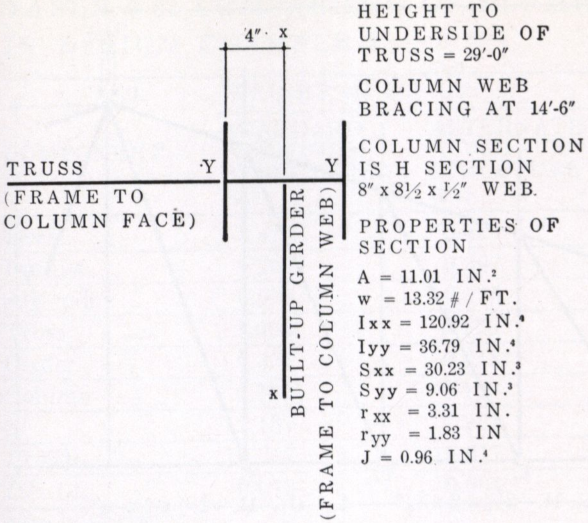


Figure 6-38: Column section and framing.

therefore

$$f_b = (16{,}500 - 4{,}180)\left(1 - \frac{4180}{6800}\right) =$$

$$4750 \text{ psi} > 3000 \text{ psi}$$

(*b*) *Check for failure of column by buckling normal to plane of bending forces*

$(l/r)_{y\ \text{actual}} = 95$

$$f_b = f_B\left(1 - \frac{f_c}{F_{cn}}\right)\left(1 - \frac{f_c}{F_{ce}}\right)$$

$F_{cn} = 8200$ psi (from Figure 2, ASCE Specifications —Partial restraint at ends)

$F_{CE} = 6720$ psi

where

F_{cn} = the allowable working stress for a member considered as an axially loaded column tending to fail in a direction normal to the plane of bending forces (psi)

$F_{CE} = \dfrac{74{,}000{,}000}{(l/r)^2}$ and (l/r) is in the plane of the bending forces

therefore

$$f_b = 16{,}500\left(1 - \frac{4180}{8200}\right)\left(1 - \frac{4180}{6720}\right) =$$

$$3050 \text{ psi} > 3000 \text{ psi}$$

Wind bracing and bottom chord bracing have not been considered inasmuch as their design interposes no special problems or procedures.

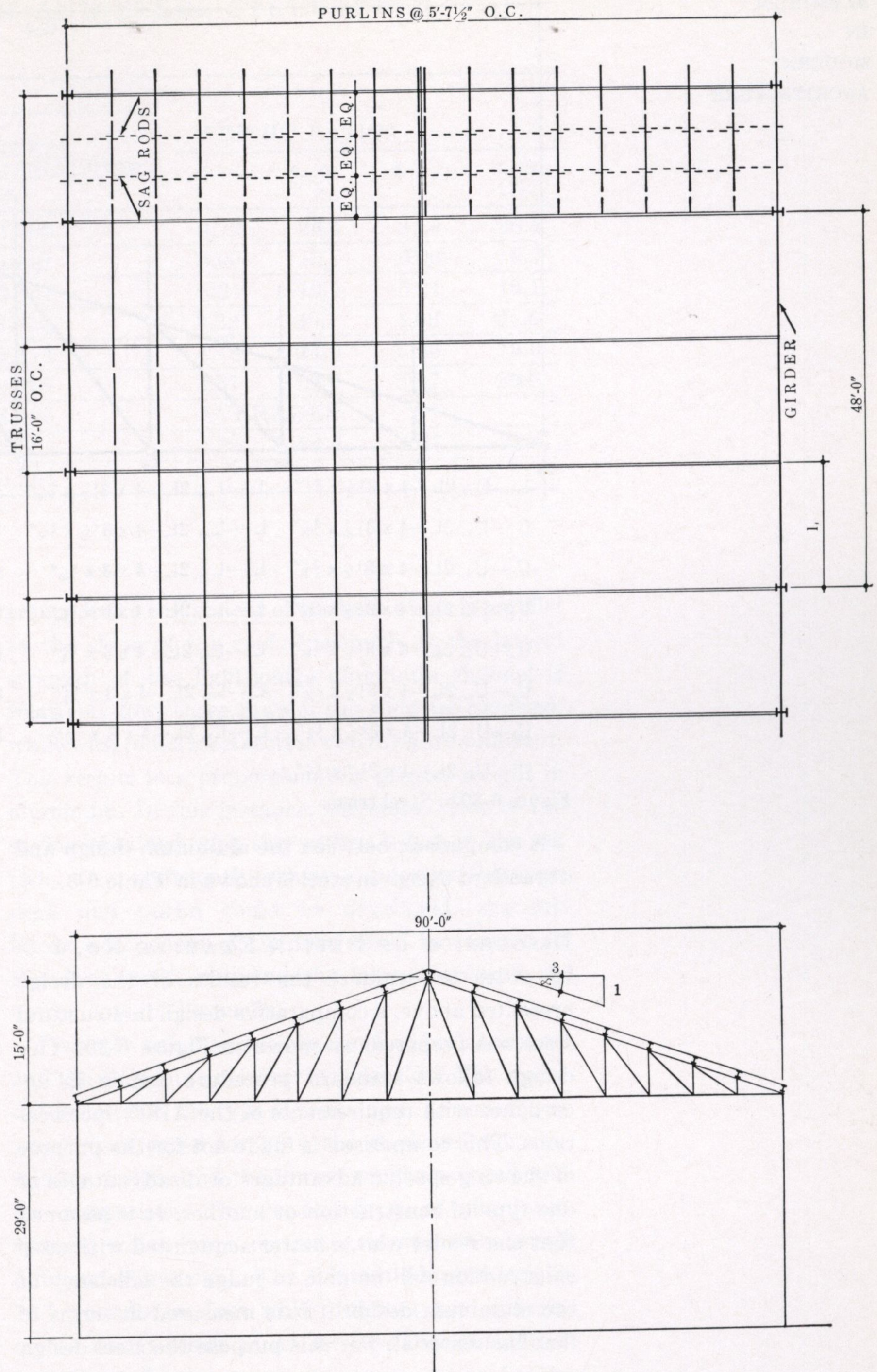
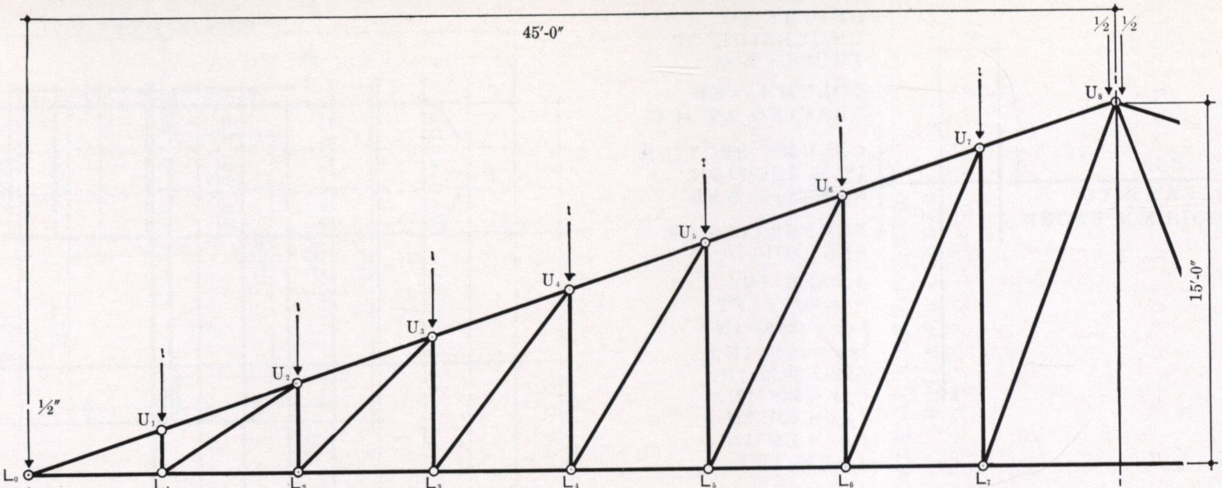


Figure 6-39a: Steel framing.



L_0—U_1, 2L—4 x 3½ x 3/8″	L_0—L_1, 2L—4 x 3½ x 5/16″	U_1—L_1, 1L—2½ x 2 x 3/16″	L_1—U_2, 1L—2½ x 2 x 5/16″
U_1—U_2, 2L—4 x 3½ x 3/8″	L_1—L_2, 2L—4 x 3½ x 5/16″	U_2—L_2, 1L—2½ x 2 x 3/16″	L_2—U_3, 1L—2½ x 2 x 5/16″
U_2—U_3, 2L—4 x 3½ x 3/8″	L_3—L_4, 2L—4 x 3 x 5/16″	U_3—L_3, 1L—2½ x 2½ x 3/16″	L_3—U_4, 1L—2½ x 2 x 5/16″
U_3—U_4, 2L—4 x 3½ x 5/16″	L_4—L_5, 2L—4 x 3 x 5/16″	U_4—L_4, 1L—3½ x 3½ x ¼″	L_4—U_5, 1L—2½ x 2 x 5/16″
U_4—U_5, 2L—4 x 3½ x 5/16″	L_5—L_6, 2L—4 x 3 x ¼″	U_5—L_5, 2L—2½ x 2 x ¼″	L_5—U_6, 1L—2½ x 2 x 5/16″
U_5—U_6, 2L—4 x 3½ x 5/16″	L_6—L_7, 2L—4 x 3 x ¼″	U_6—L_6, 2L—2½ x 2 x ¼″	L_6—U_7, 1L—2½ x 2 x 5/16″
U_6—U_7, 2L—4 x 3½ x ¼″	L_7—L_7, 2L—4 x 3 x ¼″	U_7—L_7, 2L—3 x 2 x ¼″	L_7—U_8, 1L—2½ x 2 x 5/16″
U_7—U_8, 2L—4 x 3½ x ¼″			

Figure 6-39 b: Steel truss.

A comparison between the aluminum design and a standard design in steel is shown in Table 6-3.

Discussion of Design Example No. 1

In order to evaluate the results of the design presented above, a comparative design in structural steel was prepared, as shown in Figure 6-39. This design follows standard procedure and is in accordance with requirements of the AISC Specifications. This comparison is made not for the purpose of showing specific advantages or disadvantages of one type of construction or another. It is assumed that the reader who is better acquainted with steel construction will be able to judge the efficiency of the aluminum design if it is measured in terms of familiar material. For this purpose the steel design arrived at represents the average practice. With more ingenious or more refined design methods, better results could probably have been obtained, but this would have reduced its value as a "measuring rod."

The steel structure consists of steel trusses with rolled purlins supporting a 21-gauge corrugated steel deck weighing 1.50 pounds per square foot. All essential dimensions and live loads are identical to those of the aluminum structure. For the purlins the cantilever-hung bay system is used. The results of this comparison are shown in Table 6-3.

It will be observed that the weight of the individual aluminum members vary from a maximum of 30.1 percent to a minimum of 16.7 percent of the weight of the corresponding steel members. The maximum corresponds approximately to the direct substitution of an aluminum member for a steel member of equal size. The minimum approaches the condition of equal cost for aluminum and steel members (see Chapter 5). Besides the weight comparison, the dead-load, live-load ratio of this structure is quite revealing. This ratio is 0.28 for the steel structure; *i.e., for each pound of live load supported, 0.28-pound of steel are required; while for the two aluminum designs considered, 0.07-pound*

TABLE 6-3: COMPARISON OF ALUMINUM AND STEEL STRUCTURES IN DESIGN EXAMPLE 1

COMPONENT	WEIGHT IN PSF OF: STANDARD ALUMINUM STRUCTURE (g_a)	ALTERNATE ALUMINUM STRUCTURE (g'_a)	STEEL STRUCTURE (g_s)	WEIGHT RATIOS g_s/g_a	g_a/g_s (%)	g_s/g'_a	g'_a/g_s (%)
Deck	0.420	0.420	1.590	3.79	26.4	3.79	26.4
Purlins	0.267	0.267	1.601	6.00	16.7	6.00	16.7
Sag rods	0.025	0.025	0.131	5.24	19.1	5.24	19.1
Truss	1.005	0.822*	3.340	3.32	30.1	4.06	24.6
Girder	0.331	0.248*	1.378	4.16	24.0	5.56	18.0
Column	0.139	0.139	0.469	3.37	29.6	3.37	29.6
Σ	2.187	1.921	8.509	AVERAGES:			
LL/DL	13.717	15.617	3.526	4.31	24.3	4.67	22.4
DL/LL	0.073	0.064	0.284				

Note: $LL = 30$ PSF.
(*) Alternate design used on truss and girder only.

or 0.064-pound of aluminum are required to support one pound of live load.

For the individual components the following additional observations can be made:

Deck: The design of this component was essentially restricted to the selection of commercially available products in either material. Deeper corrugations than ⅞-inch would result in a somewhat lighter deck.

Purlins: The design of these members represents an interesting example, as considerable weight saving was achieved even though the depth of the aluminum member is *less* than that of the steel section used. This is due to the lack of sufficiently small rolled steel sections. The use of a light-gauge section for these relatively light loads would lead to weight saving in any material; in aluminum this solution became especially advantageous because the deflection is not critical in the continuous purlins. It is also interesting to note that if, instead of the 8-inch light-gauge aluminum channel section weighing 1.50 pounds per lineal foot, extruded standard channels were used, the lightest available member would be a 5-inch channel of 2.38 pounds weight. Since deflection becomes the governing criterion for the 5-inch depth, either 2014 or 6061 alloy could be used.

Sag Rods: The function of these sag rods is to transmit the component of the load which is parallel to the slope of the roof. Inasmuch as the lateral strength of the light-gauge aluminum channel is relatively low, three rows of sag rods are required, while with rolled steel section two rows are sufficient. This results in a proportionately greater weight in aluminum. In this instance, therefore, some of the saving obtained with the purlins is lost in the sag rods. If a sufficiently strong connection between deck and purlin could be developed, the full lateral component of the load could be resisted in the deck itself, reducing the lateral strength requirements in the purlin.

Truss: In this instance the depth of both the steel and the aluminum member are identical. The major difference is in the type of truss used. Various types were investigated for both the steel and the aluminum design, and the lowest weight was selected for comparison. The various types of aluminum trusses, which were checked, showed only small differences in weight. The solution adopted weighs 16.1 pounds per foot while different bar arrangements would result in an increased weight of 1-2 pounds per foot.

On the other hand, significant savings can be obtained if the web members of the truss are made of more efficient pipe sections. The cord members were changed into "T" sections to permit connec-

tion of the web members. This alternate truss becomes nearly 19 percent lighter than the conventional design using angle members.

Girder: The significant difference between the steel and the aluminum girder is that the latter is a built-up section, since rolled or extruded members in the required size are not available. The weight of the built-up aluminum girder is not very sensitive as to variation in depth. The 40-inch deep member used weighs 29.8 pounds per foot, and since either an increase or decrease of 4 inches in depth would result in a change in weight of 1.0 pound per foot, the optimal depth therefore is the depth selected.

The steel section used is the most economical for the required section modulus and laterally unbraced span. If, instead of the selected 30 WF 124 steel member, a built-up section of greater depth is substituted to achieve weight saving, insufficient lateral stability results. Therefore, in the steel design, the rolled section is the most economical size. On the other hand, savings can be obtained in the aluminum member if, as shown in the alternate design, a partial-tension-field girder is substituted for the conventional built-up section. This results in a weight reduction of 25 percent, but the added fabrication required for this girder will be reflected in the cost saving achieved.

Columns: The least favorable weight relationship (with the exception of the sag rods) is exhibited in the columns. This is to be expected in view of the discussion on this subject in Chapter 5. An additional limitation is the availability of standard wide-flange aluminum sections; the maximum depth with 8-inch wide flange is only 8 inches. In the steel design the column used is 10 inches deep. The use of a shallower aluminum member therefore results in a relatively higher weight. If a special or built-up section had been used, further weight reduction could have been obtained.

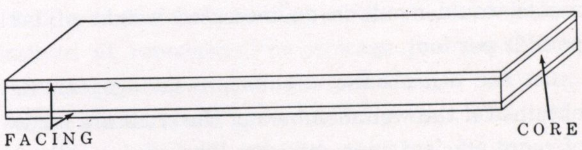


Figure 6-40: Sandwich construction.

6.4 SANDWICH CONSTRUCTION

The need for a structural element which is strong and stiff and also light in weight sparked the development of new constructional techniques. Research in the aircraft field led to the significant fact that a composite structure with thin, strong facings, bonded to a thick lightweight core, satisfies these requirements. The development of sandwich construction has been materially affected by the relatively recent advances in adhesives and fabricating techniques, and also by the availability of numerous facing and core materials.

The sandwich (Figure 6-40) is not a material having unique mechanical properties; rather it is a *structure* which must be designed for the particular uses to which it will be subjected. The composition of the sandwich is limited only by the availability of materials and the engineer's ingenuity.

Some of the materials which are presently used in the manufacture of sandwich structures are:

Facings: Aluminum, magnesium, steel, plywood, fiberboards, asbestos board and resin-treated glass-cloth, fabric and paper.

Core: Wood, plywood, fiberboard, cellular cellulose acetate, expanded rubber, foamed polystyrene, calcium alginate, foamed-in-place polyesterisocinate resin, honeycombed glass-cloth, paper, aluminum foil and waffle-type glass-fiber mat.

The current trend in sandwich construction is the metal-faced honeycomb-cored sandwich. In aluminum construction, the facings are frequently alclad and the honeycomb core is phenolic-resin impregnated fabric or paper. Table 6-4 lists various core materials and results of tests on these materials.

The primary users of sandwich construction have been the aeronautical, transportation and building industries, with special emphasis on the aeronautical industry.

In recent years, the use of this material in the building field has become widespread. Sandwich construction is used for floor and roof decks, partitions, spandrels and bearing walls. Applications for doors and furniture are also common. The widest use, however, is found in connection with

TABLE 6-4 MECHANICAL PROPERTIES OF SOME LOW-DENSITY CORE MATERIALS

MATERIAL	SPECIFIC GRAVITY	GROSS DENSITY #/FT³	CONDITIONING PRIOR TO TEST	COMPRESSION: STRENGTH PSI					TENSILE STRENGTH PSI	SHEAR: STRENGTH PSI		SHEAR: MODULUS OF RIGIDITY PSI		
				STRENGTH PSI	PROPORTIONAL LIMIT STRESS PSI	MODULUS OF ELASTICITY PSI				STRENGTH PSI		MODULUS OF RIGIDITY PSI		
				L	L	L	R	T		LT	LR	LT	LR	RT
Balsa wood	0.08	5.0	9-12% E.M.C.	640–530	305–300	205,000	12,000	3,800	...	150	140	8,900	12,300	1,300
Cellular cellulose acetate	0.10	6.2	75°F—64% R.H.	164	79	30,600	23,600	5,000	316	117	...	4,400	...	...
Aluminum foil honeycomb														
(Perforated Al 0.0021-in. foil 3/8″ cell)	0.055	3.4	75°F—64% R.H.	206	...	145,400	...	...	[b]306	[c]146	[c]62	32,900	12,600	...
(Perforated Al 0.0060-in. foil 3/8″ cell)	0.134	8.4	75°F—64% R.H.	976	...	421,200	...	...	[b]419	[b]183	[b]231	95,100	34,900	...
Cotton fabric honeycomb														
(4-oz duck 7/16″ cell)	0.060	3.7	75°F—64% R.H.	190	97	24,700	11	25	283	146	82	5,600	2,800	...
(4-oz duck 7/16″ cell)	0.147	9.2	75°F—64% R.H.	774	...	75,200	...	...	[b]365	[b]317	[b]157	14,200	5,700	...
Glass fabric honeycomb														
(1/4″ cell WESTPLAK "B-4" polyester-fabric 108)	0.064	4.0	75°F—64% R.H.	295	...	62,400	...	...	[b]299	[b]175	[c]63	8,800	2,800	...
(1/4″ cell WESTPLAK "B-6" polyester-fabric 112)	0.096	6.0	75°F—64% R.H.	499	...	91,300	...	...	[b]268	[b]193	[b]109	12,900	4,800	...
Glass mat—"Waffil"														
(0.28″ polyester)	0.150	9.4	75°F—64% R.H.	691	...	29,300	...	...	[c]163	[c]100	...	8,800	...	...
(0.30″ polyester)	0.199	12.4	75°F—64% R.H.	678	...	34,600	...	...	[c]183	[b]113	...	11,400	...	...
Paper honeycomb														
(Paper core in T-1-P-7 sandwich) [U.S. Plywood Corp.]	...	...	75°F—64% R.H.	512	...	42,300	...	...	[b]184	[b]152	[c]135	14,900	9,100	...
(Paper core in T-1-P-7 sandwich) [U.S. Plywood Corp.]	...	...	80°F—97% R.H.	327	...	25,600	...	...	[b]105	[b]125	[b]93	10,200	6,000	...
I4 AF Kraft paper 4.1 mils (NACA-TN-1529)	0.10	6.2	75°F—65% R.H.	490	190	72,500	100	110	340	270	200	17,700	11,600	...

REMARKS—The orientation for the various materials is as follows:

1. Balsa wood—(L) direction of grain, (R) radial direction, (T) tangential direction.
2. Cellular cellulose acetate—(L) direction of slab thickness, (R) direction of slab width, (T) direction of slab extrusion.
3. Cellular hard rubber—(L) direction of slab thickness, (R) direction of slab width, (T) direction of formed length.
4. Honeycomb materials—(L) direction of flutes, (R) direction perpendicular to flutes & perpendicular to planes of corrugated sheets, (T) direction perpendicular to flutes & parallel to planes of corrugated sheets.

Stresses indicated in table are stresses of gross area.

The mode of failure, when known, is indicated by either ([c]) if core failed or ([b]) if failure occurred in the bond or facing.

Table extracted from "Symposium on Structural Sandwich Constructions," June 21, 1951—American Society for Testing Materials.

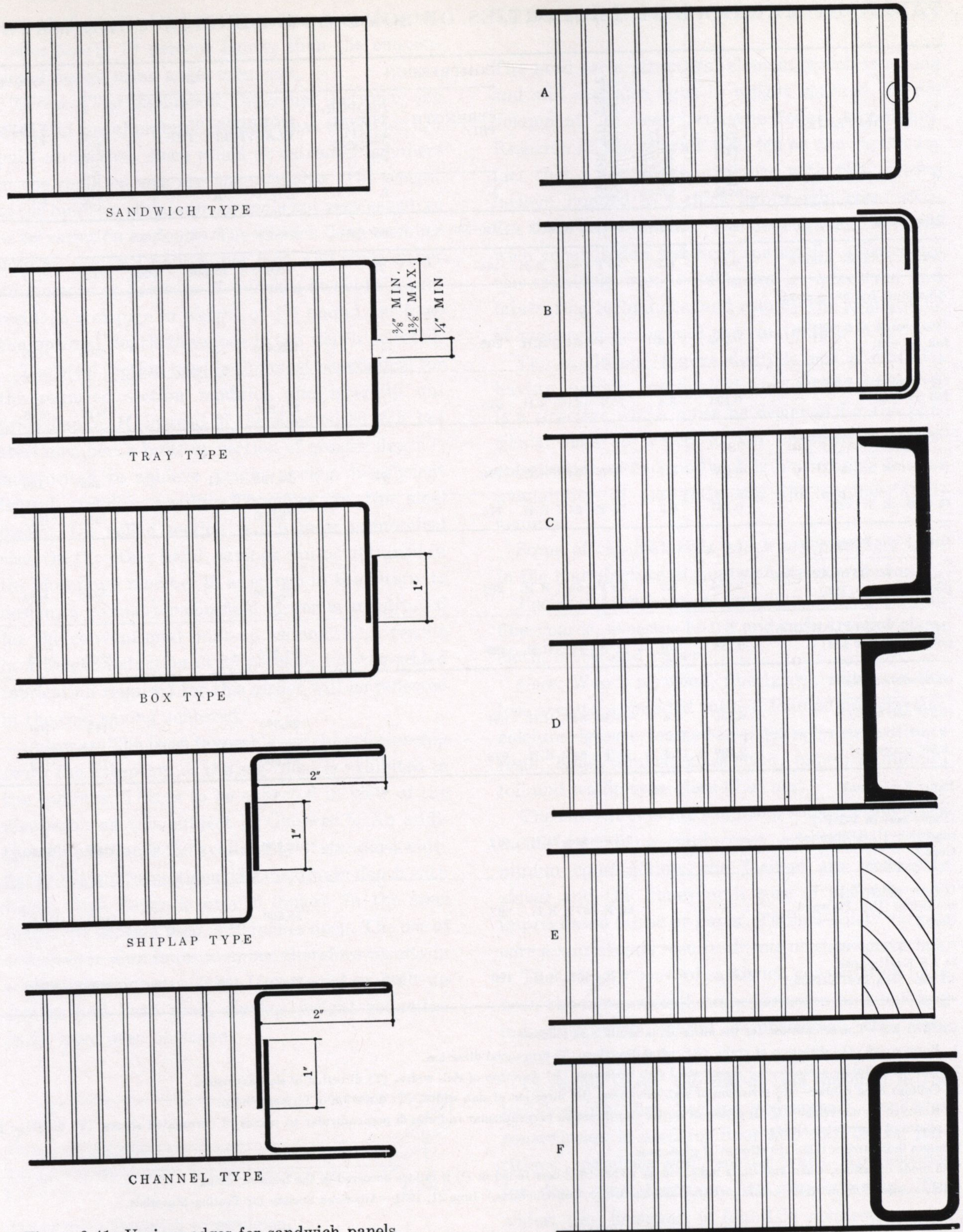


Figure 6-41: Various edges for sandwich panels.

prefabrication, where the durable finished surface, light weight and good thermal characteristics provide the nearly ideal prefabricated element.

The requirements for such application differ greatly from the original use of sandwich construction in aircraft. The most frequent considerations in the design of sandwich panels in building construction are as follows:

(a) The design is affected in the first place by cost factors rather than favorable strength-weight relationships.

(b) The stiffness of the panels is usually more critical than ultimate strength. The useful service limit is governed by limiting deformations and also by resistance and indentation under concentrated load applications. In panels used as walls or partitions, the "racking strength," i.e., the ability to transmit wind at seismic shear to the foundations without undue deformation, is important.

(c) Edge members of aluminum or other metals, of wood, or of extruded plastics are required in most installations (Figure 6-41).

(d) The joint between individual panels is the most vital detail of the construction. Joints are detailed to provide structural integrity, but "through-thermal" conductance is undesirable if condensation is to be avoided and heat losses reduced. The joints also must be tight enough to prevent both air and water leakage (Figure 6-42).

(e) The thermal conductance of the panel is important. The low-density core can often be used as bulk insulation, while the aluminum facing provides reflective insulation and also acts as vapor barrier. (See Section 8.3).

In the following sections of this chapter the solution of the structural problems connected with the design of sandwich panels in building applications is discussed. The complete design of the panels, however, must incorporate all the above listed requirements which involve many aspects not directly related to structural integrity.

In the sandwich structure, the function of the facing is to carry the stresses due to the loading, whereas the function of the core is to space the facings so as to obtain sufficient flexural rigidity and provide enough support to make them elastically stable under high stresses.

The important mechanical properties of a core material are tensile strength, compressive strength and modulus of elasticity in the direction perpendicular to the plane of the facings, shear strength in planes parallel to the facings, and modulus of rigidity measured in planes perpendicular to the facings.*

HONEYCOMB CORES: The compressive strength of the honeycomb core was found to be affected by the shape of the cells of the honeycomb. Also it was found that for any given weight of honeycomb structure, the strongest honeycomb will be that in which the cell is a square wherein the double thickness walls are virtually eliminated** (see Figure 6-43).

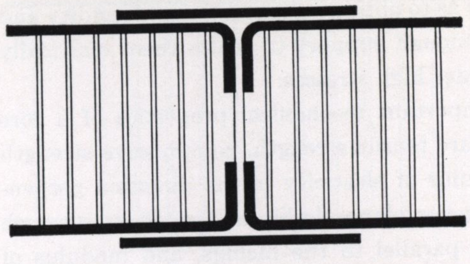
Figure 6-44 shows the increase of apparent compressive strength (compressive strength in gross area) of hexagonal honeycomb cores tested parallel to flutes with decreasing length of double-thickness wall. The curves of Figure 6-44 apply only when the cell walls buckle at stresses less than the compressive strength of the material. When the cell walls are sufficiently thick to preclude buckling, but will fail in compression, the *apparent compressive strength of the honeycomb will be directly proportional to the apparent specific gravity.* It has also been shown that the compressive strength was affected by the kind of resin employed in the manufacture of the structure and that, in the case of kraft paper, a 50 to 55 percent resin impregnation achieves maximum results for mechanical properties.

If the compressive and shear strength for a specific material and shape of cells have been determined by test, then these values can be computed for any thickness of the cell wall. For compressive strength*** (see Page 172):

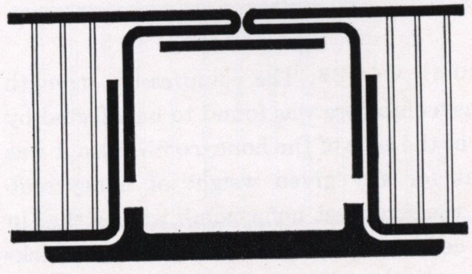
* AN INVESTIGATION OF MECHANICAL PROPERTIES OF HONEYCOMB STRUCTURES MADE OF RESIN-IMPREGNATED PAPER. C. B. Norris and G. E. Mackin—NACA, TN 1529.

** EFFECT OF CELL SHAPE ON COMPRESSIVE STRENGTH OF HEXAGONAL HONEYCOMB STRUCTURES, L. A. Ringelstetter, A. W. Voss and C. B. Norris—NACA, TN 2243.

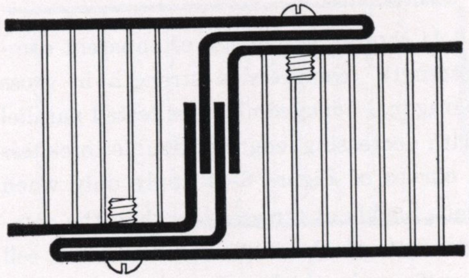
*** Norris and Mackin op. cit.—p. 7



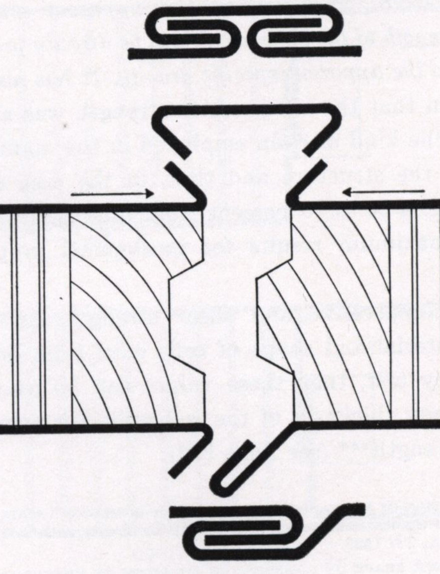
A



B



C



D

$$\frac{P_{s1}}{P_{s2}} = \left(\frac{h_1}{h_2}\right)^{2/3} = \left(\frac{g_{a1}}{g_{a2}}\right)^{2/3} \text{ approx.}$$

where P_s = specific compressive strength, psi, (apparent compressive strength divided by apparent specific gravity)

h = thickness of cell wall (inches)

g_a = apparent specific gravity (gross specific gravity of core)

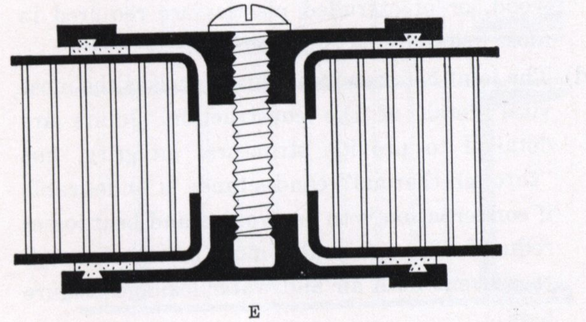
Subscripts 1 and 2 refer respectively to the prototype and the material with which it is compared.

For shear strength**

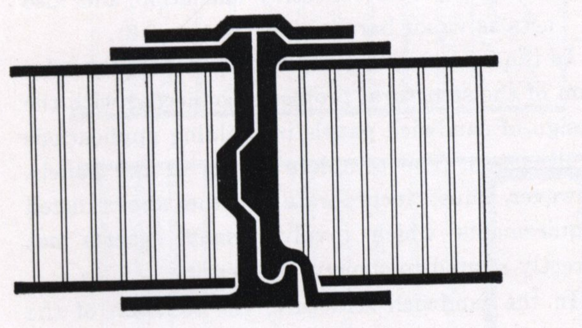
$$\frac{\tau_{s1}}{\tau_{s2}} = \frac{h_1}{h_2} = \left(\frac{g_{a1}}{g_{a2}}\right)\left(\frac{\beta_1}{\beta_2}\right)$$

where

** Adapted from ANALYSIS OF SHEAR STRENGTH OF HONEYCOMB CORES FOR SANDWICH CONSTRUCTION, NACA, TN 2208—Werren and Norris.

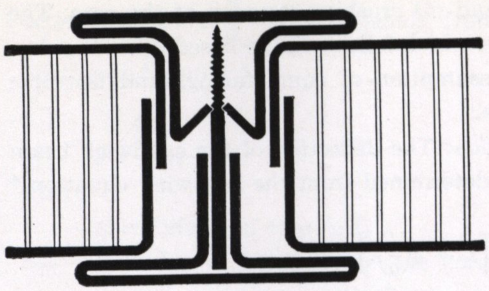


E

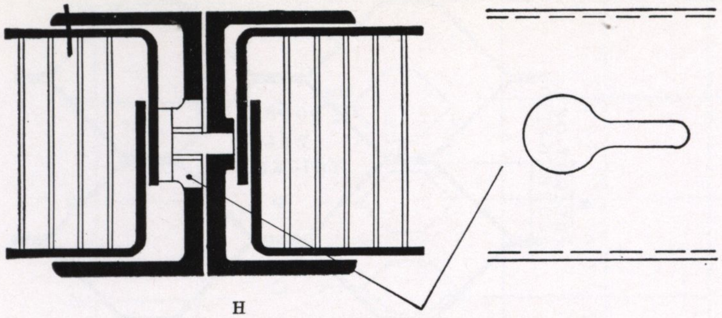


F

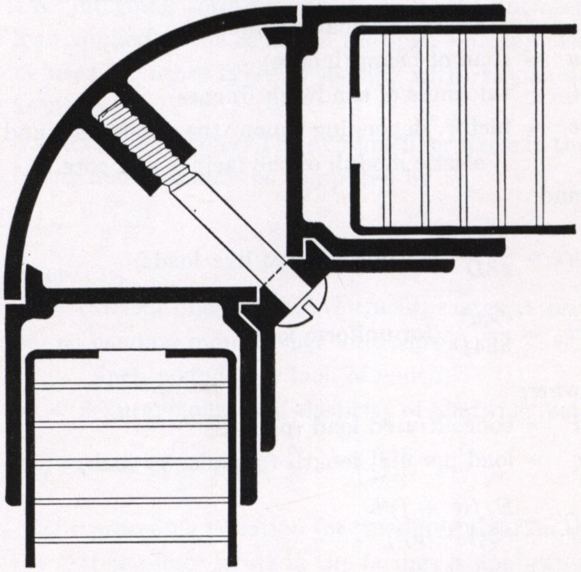
Figure 6-42: Joint details. (Concluded on Page 173.)

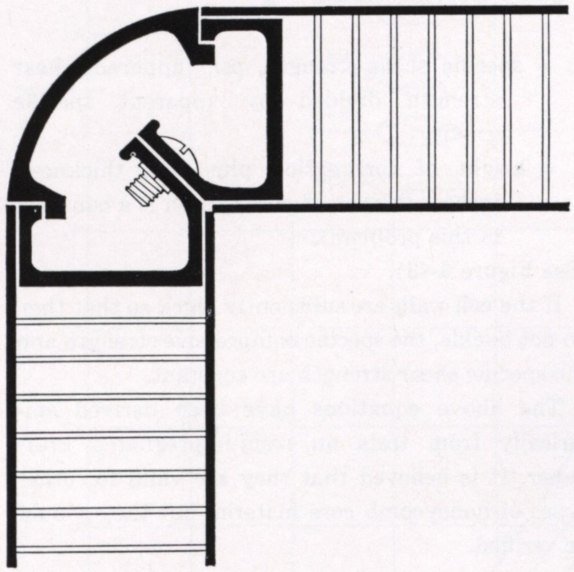


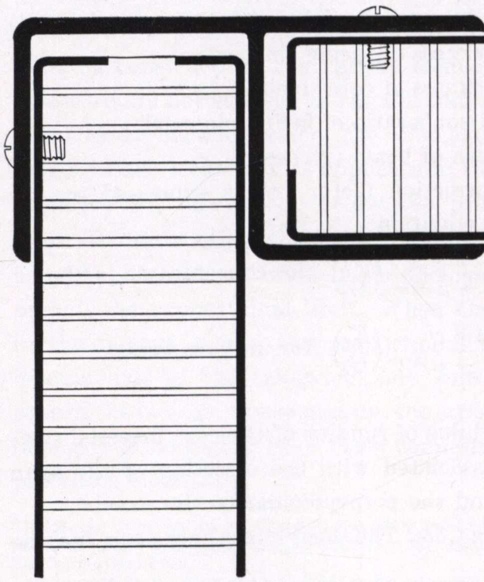
G



H







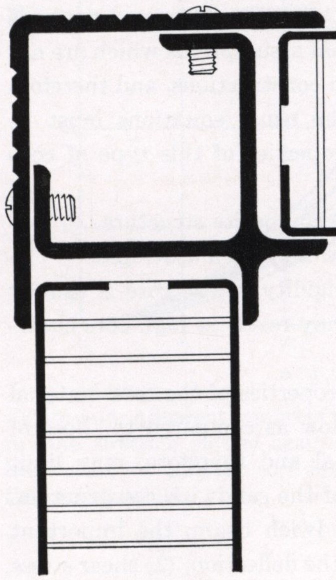


Figure 6-42: Joint details, concluded from Page 172.

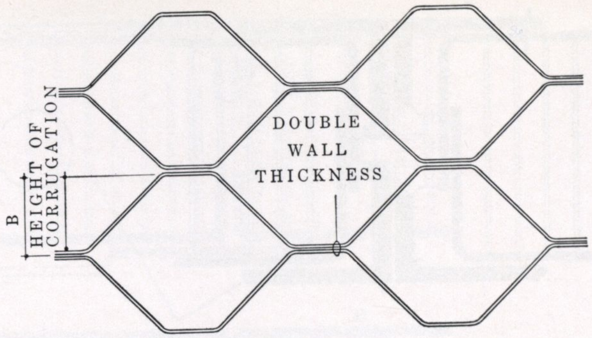


Figure 6-43: Honeycomb.

τ_s = specific shear strength, psi, (apparent shear strength divided by apparent specific gravity)

β = height of corrugation plus wall thickness, inches, (height of corrugation is a constant in this problem).

(See Figure 6-43).

If the cell walls are sufficiently thick so that they do not buckle, the specific compressive strength and the specific shear strength are constant.

The above equations have been derived empirically from tests on resin-impregnated kraft paper. It is believed that they are valid for other types of honeycomb core material but they should be verified.

DESIGN CONSIDERATIONS: The usual methods of design are based upon assumptions which are not applicable to sandwich constructions, and therefore may not be used. The usual equations must be modified to fit the properties of this type of construction:

(1) The sandwich is a composite structure.
(2) The materials used may be anisotropic.
(3) The modulus of rigidity of the core is usually very low, which may result in high core shear-deformation.
(4) The mechanical properties of the core material are usually very low as compared to those of the facing material and therefore, may limit the performance of the sandwich construction.

When designing a sandwich beam, the important considerations are (1) the deflection, (2) shear stress in core, (3) compressive and tensile stresses in facings and (4) crushing strength of the core. The equations which follow will be based upon the simplified assumption of equal facings and isotropic materials.

Deflection: The deflection of the sandwich beam may be determined from the following equation:*

$$w = w_o\left[1 + e\left(\frac{t}{a}\right)^2\right]$$

where

w_o = central deflection without correction for shear-deformation (inches)

a = span of beam (inches)

t = thickness of sandwich (inches)

e = factor depending upon the thickness and elastic moduli of the facings and core

and

$$w_o = \frac{Pa^3}{48D} \text{ (for concentrated live loads)}$$

$$w_o = \frac{5qa^4}{384D} \text{ (for uniform load)}$$

where

P = concentrated load (pounds)

q = load per unit length (pounds per inch)

$$D = \frac{E_f f(c+f)^2 b}{2(1-\mu_f^2)}$$

in which

E_f = modulus of elasticity of facing material (psi)

f = thickness of facing (inches)

c = thickness of core (inches)

μ_f = Poisson's ratio of facing material

b = width of beam (inches)

The correction factor "e" is expressed by the following equation:

$$e = \frac{6\,cf}{(1-\mu_f^2)t^2}\left(\frac{E_f}{G_c}\right) \text{ (for concentrated loads)}$$

$$e = \frac{4.8\,cf}{2(1-\mu_f^2)t^2}\left(\frac{E_f}{G_c}\right) \text{ (for uniform loads)}$$

where

G_c = modulus of rigidity of the core material (psi) associated with the direction of the span and the perpendicular to the panel

Shear in Core: The shear stress in the core may be

* SANDWICH CONSTRUCTION IN THE ELASTIC RANGE by H. W. March—Symposium on Structural Sandwich Construction—June 12, 1951.

determined when $\frac{E_{ca}}{E_f}$ is very small, from the approximate formula:*

$$\tau = \frac{P}{b(t+c)}$$

where

τ = shear stress in core (psi)

E_{ca} = modulus of elasticity of the core material (psi) (associated with the direction of the span)

The foregoing formula applies to a concentrated load applied at the center of the span—it may also be used for other types of loading with reasonable accuracy.

Stresses in Facings: The extreme fiber stress in the facing material may be computed by

$$\sigma_f = \frac{6\,E_f M}{E\,t^2}$$

where

σ_f = extreme fiber stress in the facing material (psi)

M = bending moment per unit width (inch-pounds per inch of width)

E = flexural modulus of elasticity of sandwich (psi)

and $E = E_{ca}\left(\frac{c}{t}\right)^3 + E_f\left[1 - \left(\frac{c}{t}\right)^3\right]$

The preceding equation for the determination of the extreme fiber stress in the facings is applicable to constructions wherein the stresses encountered are below the proportional limit of the material. In building construction, the various elements of the structure are not stressed to the ultimate, but only to stresses beyond which the element will no longer be serviceable in its application; the stresses therefore will always be below the proportional limit. In fields other than the building industry, however, allowable stresses in the facings may approach the proportional limit. When the stresses in the facings exceed the proportional limit, the neutral axis of the sandwich may split and approach the facings. Consequently, the stresses in the facings will be higher than those computed by the preceding equation.†

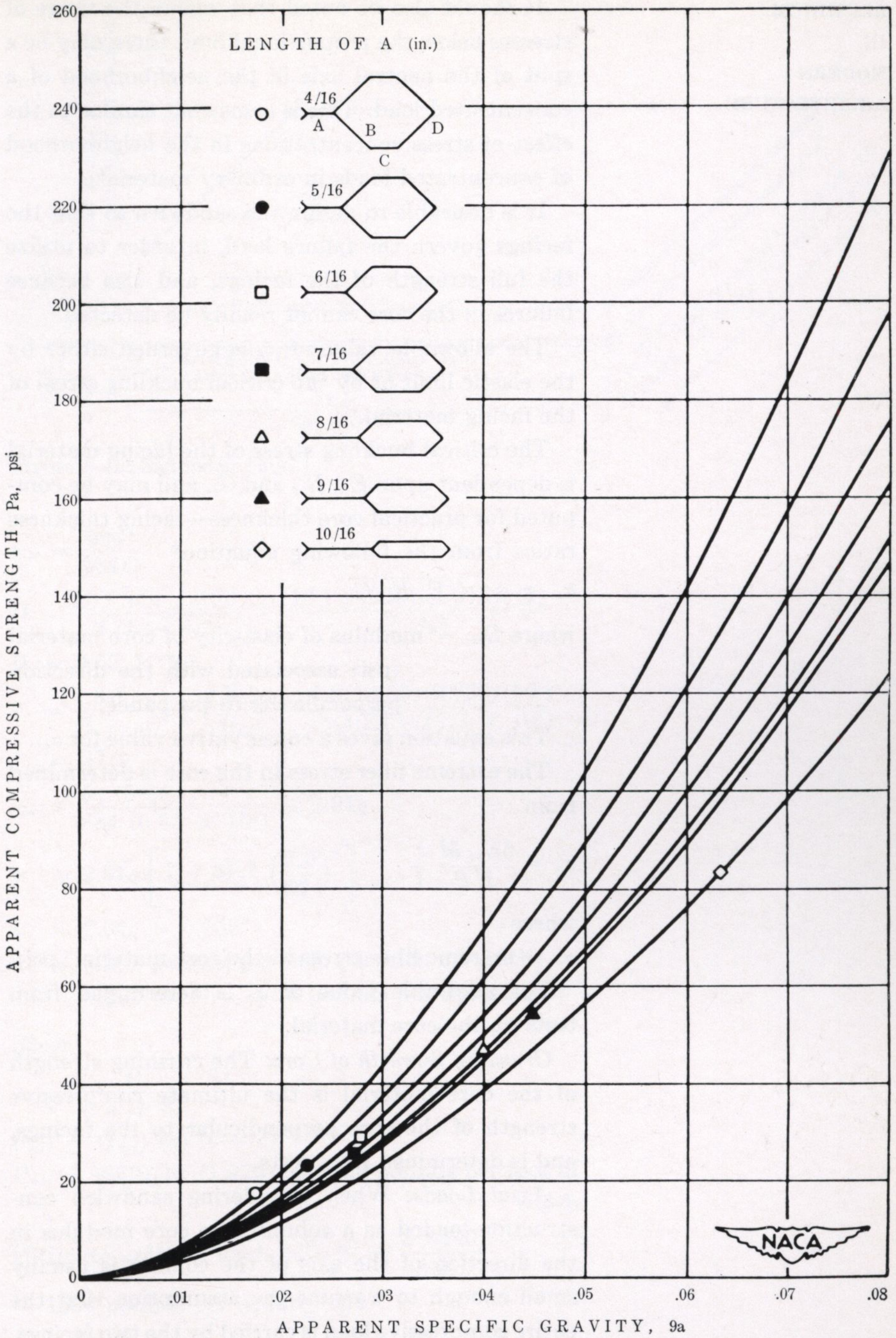


Figure 6-44: Apparent compressive strength of hexagonal honeycomb cores tested parallel to flute direction plotted against apparent specific gravity of test specimens. Average test values for different core shapes are shown by point symbols; curves are based on theoretical values.

* STRENGTH OF SANDWICH CONSTRUCTION, C. B. Norris—Symposium on Structural Sandwich Constructions—June 21, 1951, American Society for Testing Materials.

† SYMPOSIUM ON STRUCTURAL SANDWICH STEEL—June 21, 1951. C. B. Norris.

It should also be noted that within the range of stresses below the proportional limit there may be a split of the neutral axis in the neighborhood of a concentrated load. This is somewhat similar to the effect of stress concentrations in the neighborhood of concentrated loads in ordinary materials.

It is desirable to design the sandwich so that the facings govern the failure load, in order to utilize the full strength of the facings, and also because failures in the core cannot readily be detected.

The allowable value of σ_f is governed either by the elastic limit or by the critical buckling stress of the facing material.

The critical buckling stress of the facing material is dependent upon E_f, E_{cb} and G_c, and may be computed for practical core thickness—facing thickness ratios from the following equation*

$$\sigma_{cr} = \tfrac{1}{2}\sqrt[3]{E_f\,E_{cc}\,G_c}$$

where E_{cb} = modulus of elasticity of core material (psi) associated with the direction perpendicular to the panel

This equation gives a conservative value for σ_{cr}.

The extreme fiber stress in the core is determined from

$$\sigma_c = \frac{6E_{cc}\,M}{E\,t^2}\,\frac{c}{t}$$

where

σ_c = extreme fiber stress in the core material (psi).

The allowable value of σ_c is determined from tests on the core material.

Crushing Strength of Core: The crushing strength of the core material is the ultimate compressive strength of the core perpendicular to the facings, and is determined from tests.

Axial Loads: When considering sandwich construction loaded as a column, the core modulus in the direction of the axis of the column is usually small enough to warrant the assumption that the entire compressive load is carried by the two facings.

The column is subject to failure due to the following: Overall buckling, wrinkling of the facings, and in the particular case of the grid type core, such as the honeycomb, local buckling of the facing into the grid.

Tests have shown that the latter two conditions are encountered only when the slenderness ratio is very small.** In normal building construction practice such small slenderness ratios would not be encountered; therefore, it is necessary to compute only the critical buckling load for overall buckling failure.

The critical Euler buckling load of a simply supported column may be determined from the following equation***

$$P_{cr} = \frac{P_1\left[P_2 + G_c\,bc\left(1 + \frac{P_2}{P_1}\right)\right]}{P_1 + G_c\,bc}$$

where

$$P_1 = \frac{\pi^2}{2}(c+f)^2 fb\,\frac{E_f}{L^2}$$

and P_1 is the buckling load of a column of which the core is perfectly rigid in shear and f^3 is considered negligibly small, and

$$P_2 = \frac{\pi^2}{6}\,f^3 b\,\frac{E_f}{L^2}$$

and P_2 is the buckling load when the core is considered to have no shearing rigidity and therefore the facings are considered as two independent columns.

L = length of the column (inches)
b = width of the column (inches)

Simply supported rectangular sandwich panels which are subjected to combined compressive edge loads and lateral forces have been investigated, and formulas derived which permit calculation of the deflection, bending moments and reactions of the supports.†

The formulas are quite complex, but in the reference mentioned, H. W. March has presented, in the form of tables and graphs, the results of computations for square panels having shear stiffnesses within the range of practical interest.

Racking: It is possible to compute the shear resistance of sandwich panels with simply supported edges, which are subject only to shearing forces in

* ENGINEERING LAMINATES, A. G. H. Dietz—p. 71.

** Engel, Hemming, Merriman, op. cit.—p. 182

*** A. G. H. Dietz, op. cit.—p. 76

† BEHAVIOR OF A RECTANGULAR SANDWICH PANEL UNDER A UNIFORM LATERAL LOAD AND COMPRESSIVE EDGE LOADS, H. W. March—Report —1834 Forest Products Laboratory, U. S. Department of Agriculture.

the plane of the panel (racking forces). The shear resistance of the panel, in pounds per inch width of the panel, is

$S = 2f\tau$

where τ is either $\tau_{ultimate}$, the ultimate shear stress of the facing, or τ_{cr}, the critical shear buckling stress of the facing for the particular geometry of the sandwich panel. The critical shear buckling stress may be computed from the equation*

$$\tau_{cr} = k\,\frac{\pi^2 E_f}{4(1-\mu_f{}^2)}\left(\frac{c+f}{b}\right)^2$$

where

$k \;= 5.35 + 4\left(\frac{b}{L}\right)^2$ approx., and $b \leq L$

$b \;=$ width of the panel (inches)

$L \;=$ height of the panel (inches)

6.5 DESIGN EXAMPLE NO. 2

To investigate load carrying capacities of sandwich panel illustrated in Figure 6-45.

MATERIALS:

Facings: Aluminum Alloy 3003-H14

$E = 10.0 \times 10^6$ psi

$\sigma_{yield} = 21.0 \times 10^3$ psi

$\tau_{ult.} = 14.0 \times 10^3$ psi

$\mu = 1/3$

Core: Kraft paper honeycomb, resin impregnated. Type 14AF.

$E_a = 100$ psi

$E_c = 72.5 \times 10^3$ psi

$G = 17.7 \times 10^3$ psi

$\sigma_{prop\ limit} = 2$ psi

$\tau_{ult.} = 270$ psi

Ultimate compression strength in direction of cell $= 490$ psi

BEAM CHARACTERISTICS:

Deflection: Limit deflection to

$$w = \frac{a}{180} = \frac{96}{180} = 0.533\text{-inch}$$

$$w = w_o\left[1 + e\left(\frac{t}{a}\right)^2\right]$$

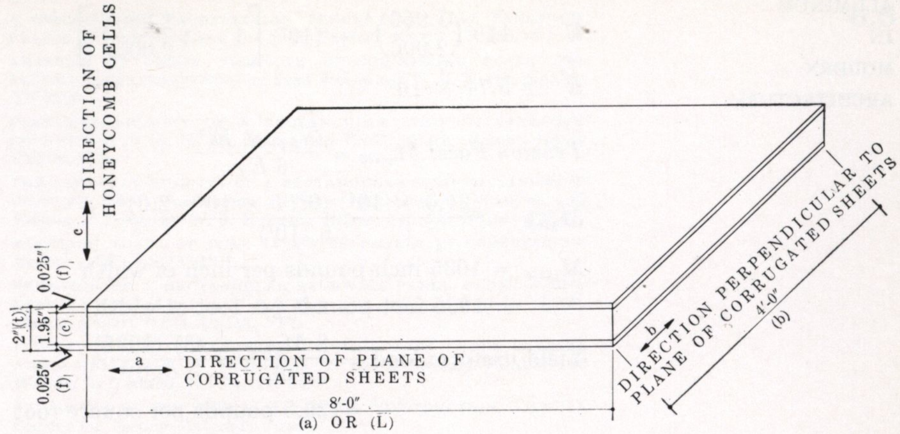


Figure 6-45: Sandwich panel.

$$w_o = \frac{5qa^4}{384D}$$

$$D = \frac{E_f f (c+f)^2 (b)}{2(1-\mu_f{}^2)} = \frac{(10^7)(0.025)(1.975)^2(1)}{2(8/9)}$$

$$D = 0.55 \times 10^6$$

$$e = \frac{4.8cf}{(1-\mu_f{}^2)t^2}\left(\frac{E_f}{G_c}\right) = \frac{4.8(1.950)(0.025)(10^7)}{(8/9)(2.0)^2(17.7\times 10^3)}$$

$$e = 37.2$$

$$w_o = \frac{5q(96)^4}{384(0.55\times 10^6)} = 2.01q$$

$$w = 2.01q\left[1 + 37.2\left(\frac{2.0}{96}\right)^2\right]$$

$$w = 2.04q = 0.533''$$

$q = 0.261$ pounds per inch per inch of width

$q = 0.261\,(144) = 37.6$ pounds per square foot

Shear

$$\tau = \frac{P}{b(t+c)}$$

$$P_{ult} = (\tau_{ult})(b)(t+c)$$

$P_{ult} = (270)(12)(1.975) = 6400$ pounds per foot of width

Ultimate uniform load $= \dfrac{2P_{ult}}{a} = \dfrac{2(6400)}{8.0}$

$= 1600$ pounds per square foot

Stress in Facings and Core

Facings: $\sigma_f = \dfrac{6E_fM}{Et^2}$

$$M = \frac{\sigma_f Et^2}{6E_f}$$

$$E = E_{ca}\left(\frac{c}{t}\right)^3 + E_f\left[1 - \left(\frac{c}{t}\right)^3\right]$$

* Engel, Hemming and Merriman, op. cit.—p. 188, also THEORY OF ELASTIC STABILITY, S. Timoshenko, McGraw-Hill Publ.—1936—p. 361.

$$E = 110\left(\frac{1.950}{2.000}\right)^3 + (10^7)\left[1 - \left(\frac{1.950}{2.000}\right)^3\right]$$

$$E \cong 0.74 \times 10^6$$

Tension Face: $M_{yield} = \dfrac{(\sigma_{f\ yield})\ Et^2}{6\ E_f}$

$$M_{yield} = \frac{(21.0 \times 10^3)\ (0.74 \times 10^6)\ (2.0)^2}{6\ (10^7)}$$

M_{yield} = 1035 inch-pounds per inch of width
= 1035 foot-pounds per foot of width

Yield uniform load $= \dfrac{8\ M_{yield}}{a^2} = \dfrac{(8)\ (1035)}{(8.0)^2}$
= 129.5 pounds per square foot

Compression Face: Check critical wrinkling stress.

$$\sigma_{cr} = (\tfrac{1}{2})\ \sqrt[3]{E_f\ E_{cc}\ G_c}$$
$$= (\tfrac{1}{2})\ \sqrt[3]{(10^7)\ (72.5 \times 10^3)\ (17.7 \times 10^3)}$$

$$\sigma_{cr} = 117.2 \times 10^3$$

$\sigma_{cr} > \sigma_{yield}$. Therefore σ_{yield} governs and loading is same as for tension face.

Core:

$$M_{\substack{prop\\limit}} = \frac{(\sigma_{c\ P.I.})Et^3}{6E_{ca}\ C} = \frac{(2)\ (0.74 \times 10^6)\ (2.0)^3}{6\ (10^2)\ (1.950)}$$

= 10,100 inch-pounds per inch of width

Prop. Limit Uniform Load ≅ 1,260 pounds per square foot

Crushing

Ultimate compressive strength of core = 490 psi. Proportional Limit Compressive strength of core = 190 psi. A customary performance requirement for floors is that the floor sustain a load of 250 pounds applied on a 1-inch diameter circle (a permanent set greater than 25 percent of maximum deflection is considered failure). This load is equivalent to 318 psi.

318 psi < 490 psi

Column Characteristics

$$P_{cr} = P_1 \frac{\left[P_2 + G_c\ bc\left(1 + \dfrac{P_2}{P_1}\right)\right]}{P_1 + G_c\ bc}$$

$$P_1 = \left(\frac{\pi^2}{2}\right)\ (c + f)^2\ fb\left(\frac{E_f}{L^2}\right)$$

$$P_1 = \left(\frac{\pi^2}{2}\right)\ (1.975)^2\ (0.025)\ (48)\left[\frac{10^7}{(96)^2}\right]$$

$$P_1 = 25.1 \times 10^3$$

$$P_2 = \left(\frac{\pi^2}{6}\right)\ (f^3)\ (b)\left[\frac{E_f}{L^2}\right]$$

$$P_2 = \left(\frac{\pi^2}{6}\right)\ (0.025)^3\ (48)\left[\frac{10^7}{(96)^2}\right]$$

$$P_2 = 1.34$$

$$P_{cr} = \frac{(25.1 \times 10^3)\left[1.34 + (17.7 \times 10^3)(48)(1.950)\left(1 + \dfrac{1.34}{25.1 \times 10^3}\right)\right]}{(25.1 \times 10^3) + (17.7 \times 10^3)(48)(1.950)}$$

P_{cr} = 24.7 × 10^3 pounds

$P_{cr} = \dfrac{24.7 \times 10^3}{48}$ = 514 pounds per inch of width

Racking:

$$S = 2f\tau$$

τ_{ult} = 14.0 × 10^3 psi

$$\tau_{cr} = (k)\frac{\pi^2\ E_f}{4\ (1 - \mu_f^2)}\left[\frac{c + f}{b}\right]^2$$

$$k = 5.35 + 4\left(\frac{b}{L}\right)^2 = 5.35 + 4\left(\frac{48}{96}\right)^2$$

$$k = 6.35$$

$$\tau_{cr} = (6.35)\ \frac{\pi^2\ (10^7)}{4\ (\tfrac{8}{9})}\left[\frac{1.975}{48}\right]^2$$

$$\tau_{cr} = 0.298 \times 10^6$$

$\tau_{cr} > \tau_{ult}$ therefore use τ_{ult}

$$S_{ult} = 2\ (0.025)\ (14.0 \times 10^3)$$

S_{ult} = 700 pounds per inch of width

BIBLIOGRAPHY

BUCKLING IN SHEAR OF CONTINUOUS FLAT PLATES by Bernard Budiansky, Robert W. Connor and Manuel Stein, NACA, NT 1565.

CRITICAL SHEAR STRESS OF AN INFINITELY LONG PLATE IN THE PLASTIC REGION by Elbridge Z. Stowell, NACA, TN 1681.

CRITICAL SHEAR STRESS OF INFINITELY LONG, SIMPLY SUPPORTED PLATE WITH TRANSVERSE STIFFENERS by Manuel Stein and Robert W. Frolich, NACA, TN 1851.

AIRPLANE STRUCTURES, Vols. I & II by Alfred S. Niles and Joseph S. Neiwell, John Wiley & Sons, 1943.

BUCKLING STRENGTH OF METAL STRUCTURES by Hans Bleich, McGraw-Hill.

THEORY OF ELASTIC STABILITY by S. Timoshenko, McGraw-Hill.

THE USE OF ALUMINIUM AS A STRUCTURAL MATERIAL by R. A. S. Jenkins, Architecture & Building 29, Nov. 1954, p. 434.

THE USE OF ALUMINIUM FOR STRUCTURAL PURPOSES by D. V. Pike, Al. Dev. Assoc. Repr. Ser. RP44, March 10, 1954.

ALUMINIUM AS A STRUCTURAL MATERIAL by M. Bridgewater, Engineering, London, June 12, 1953.

ALUMINIUM IN STRUCTURAL ENGINEERING by W. C. Devereux, The Engineer, London, Aug. 3, 1951.

STRUCTURAL APPLICATIONS OF ALUMINIUM by W. D. Devereux, J. M. Smith and J. Pike. Paper presented at the Intern. Al. Congress, Paris, June 14–19, 1954.

THE USE OF ALUMINUM IN BUILDING by J. McHardy Young, The Architects' Jour., London, July 23, 1953, p. 120.

ALUMINUM DOME—Light Metal Age, April 1954, p. 16.

DIE ALUMINIUMBRÜCKE IN DÜSSELDORF by W. Bleicher, Aluminium, Jan. 1954.

A NEW LIGHT ALLOY BASCULE BRIDGE AT ABERDEEN by E. W. Pleines, Aluminium 30, Oct. 1954, pp. 422/426.

ALUMINIUM AS A BRIDGE MATERIAL by C. Marsh, Light Metals 17, Dec. 1954, p. 376.

DEPARTMENT OF THE ARMY—STRUCTURAL DESIGN BRANCH—THIRD EDITION OF TENTATIVE SPECIFICATIONS FOR THE DESIGN

OF HIGHWAY BRIDGES AND INCIDENTAL STRUCTURES FOR MILITARY USE, 1 Aug. 1952.

ALLOWABLE STRESSES FOR CHANNELS AND Z-SECTIONS IN BENDING by B. E. Gatewood and D. W. Breuer, J. Aeron. Soc. 21, May 1954, p. 349/50.

STRUCTURAL USES FOR ALUMINUM EXTRUSIONS IN EUROPE by C. Marsh, Modern Metals 10, July 1954, p. 70/74.

ALUMINIUM AND ITS ALLOYS IN BUILDING The Aluminium Development Association, June 1953.

THE USE OF ALUMINIUM ALLOYS IN STRUCTURAL ENGINEERING, The Aluminium Development Association, Nov. 1950.

ALUMINUM STRUCTURAL DESIGN, Reynolds Metals Company.

ALCOA STRUCTURAL HANDBOOK, Aluminum Company of America.

ALUMINIUM IM INGENIEURBAU. Aluminium-Zentrale, Düsseldorf, 1955.

AN ANALYSIS OF THE COMPRESSIVE STRENGTH OF HONEYCOMB CORES FOR SANDWICH CONSTRUCTION by C. B. Norris, NACA, TN 1251.

AN INVESTIGATION OF MECHANICAL PROPERTIES OF HONEYCOMB STRUCTURES MADE OF RESIN-IMPREGNATED PAPER by C. B. Norris and G. E. Mackin, NACA, TN 1529.

EFFECT OF CELL SHAPE ON COMPRESSIVE STRENGTH OF HEXAGONAL HONEYCOMB STRUCTURES by L. A. Ringelstetter, A. W. Voss and C. B. Norris, NACA, TN 2243.

A GENERAL SMALL-DEFLECTION THEORY FOR FLAT SANDWICH PLATES by Charles Libove and S. B. Batdorf, NACA TR 899.

ANALYSIS OF SHEAR STRENGTH OF HONEYCOMB CORES FOR SANDWICH CONSTRUCTIONS by Fred Wenen and C. B. Norris, NACA, TN 2208.

FLEXURAL RIGIDITY OF A RECTANGULAR STRIP OF SANDWICH CONSTRUCTION by H. W. March and C. B. Smith, Report #1505, USDA, FPL.

THE FLEXURAL RIGIDITY OF A RECTANGULAR STRIP OF SANDWICH CONSTRUCTION (Comparison Between Mathematical Analysis and Results of Tests) by W. J. Konners, Report #1505A, USDA, FPL.

BUCKLING LOADS OF FLAT SANDWICH PANELS IN COMPRESSION, Report #1525, USDA, FPL.

BEHAVIOR OF A RECTANGULAR SANDWICH PANEL UNDER A UNIFORM LATERAL LOAD AND COMPRESSIVE EDGE LOADS by H. W. March, Report #1834, USDA, FPL.

INVESTIGATIONS OF SANDWICH CONSTRUCTIONS UNDER LATERAL AND AXIAL LOADS by Wilhelmina D. Kroll, Leonard Hordfin and William A. Garland, NACA, TN 3090.

SYMPOSIUM ON STRUCTURAL SANDWICH CONSTRUCTION, American Society for Testing Materials, June 21, 1951.

STRUCTURAL PLASTICS by H. C. Engel, Charles B. Hemming, H. R. Merriman, McGraw-Hill, 1950.

ENGINEERING LAMINATES by A. G. H. Dietz, John Wiley and Sons, 1949.

CHAPTER 7: ARCHITECTURAL DESIGN AND DETAILS

Architecture expresses the way of life of an epoch in terms of materials and building methods.

The great gothic cathedrals expressed the dominating religious idea of their time through the masterful use of cut stone. This new spatial and structural concept of lofty arches and vaults soaring to the heavens with unprecedented ease and grace on the wings of their dematerialized flying buttresses, manifested great understanding in the creative use of the structural qualities of cut stone. Despite the great advances in the theory of engineering today, we couldn't build more daring structures than the gothic cathedrals if we were limited to the same materials, equipment and skills.

Similarly today, to be creative, we must express our way of life in terms of our advanced technology. The development of science and engineering, the technological progress in communications and production have changed our way of life. Handicraft has been replaced by machine production, individual efforts by mass production, haphazard methods by processes meeting exact requirements and specifications. Consequently, the product of our work has changed.

This change has revealed itself through marked architectural trends. Modern architectural planning, design and construction methods require open, flexible spaces, large spans, large window areas, fast erection methods and decrease in field labor, permanent finishes, low maintenance cost.

This trend during recent years obviously increased the use of metals, glass and synthetic materials and encouraged the development of prefabricated elements and assemblies.

In this process, aluminum has gained an outstanding position because of its advantages, as detailed in preceding chapters. The properties of aluminum, its potentials and limitations, have been explored and are well known; production and fabricating methods are well advanced.

Yet, there remains a great challenge for the engineer and architect to take advantage of this material and its product in a creative way. Although this chapter deals with the architectural applications, we necessarily have to refer to the engineering aspects—they cannot be divorced from the architectural solutions. New construction materials, methods and elements are characterized, for example, by taking advantage of the material's tensile strength, by combining the frame with stressed covering, by combining the structural elements with the finish and with thermal and acoustical insulation. We realize more and more that the form is not an independent aim but the result of the overall process.

Yet the resulting form and appearance are an important part of the function; they determine the emotional impact and represent a cultural and spiritual value that is indispensable. For this reason, it is felt that even within the framework of the technical nature of this chapter a short discussion of the outward expression is in order.

In the beginning, man was limited to available natural materials. He employed the strictly handicraft method of production and modified only slightly the natural appearance of the clay, wood and rock. Buildings seemed to grow out of their surroundings. Later, as manual techniques came into use, repetitive elements of considerable accuracy were introduced, foreshadowing the machine-made mass production. Architectural composition in the past depended on masses, solids and openings, with mass and space remaining distinctly separate. Though frequently dominating

their surroundings, the materials used—brick, stone, wood, copper—were natural materials inherently blending with nature.

Today, light framework and transparent enclosures make it possible to visualize the shape of the building and its spaces simultaneously. This quality of transparency lays nature open to view. Polished surfaces reflect the surroundings. These provide a new way of linking the buildings to nature, although the new materials themselves are detached from nature. This represents a difference in basic concept from the architecture of the past. It should guide us in the design of architectural elements.

Some elements that originated under handicraft methods are greatly improved today by mass production—masonry blocks, cut lumber, windows, roofing, and the like. In other cases, new materials are utilized in the manufacture of conventional elements. While the material advantage of an innovation, such as greater economy or comfort, is usually recognized, the need to win consumer acceptance is often made the excuse for retaining and imitating the conventional form. This practice usually shows a lack of imagination and retards the progress of an expanding market.

By educating its merchandisers as well as the public, the aluminum industry can speed up the simultaneous development of new methods and their proper expression.

When used to the best advantage, aluminum, like every other material, determines its own scale and character. Keeping it distinctive and genuine means making a contribution to good design that will eventually lead to the best commercial promotion.

The natural materials and handicraft methods of the past produced results that evoked human understanding and appreciation—they were warm and lovable in their imperfection. Our challenge today is to produce, by machine, from our new materials qualities just as ingratiating.

An example of such an accomplishment of modern industry is the corrugated sheet. The corrugations have been devised to increase the rigidity, allowing the material to span greater distances without sagging or "oil-canning." At the same time, unhampered by conventionality, they offer new esthetic values.

The finish of aluminum also offers a challenge. Traditional, natural materials weathered gracefully by blending with nature. Aluminum, like other new materials, has yet to solve the problem of finish, not only technically but aesthetically.

These considerations point to the fact that the success of aluminum in the building industry depends upon the degree of boldness and creativeness in applying its great, and in many ways unique, inherent advantages. This will be achieved not by the rationalization of traditional building methods, but by a creative, original approach.

Although present-day construction depends on standardization for economy and perfection, the use and applications of standardized elements offer great opportunities for the creative designer. Aluminum's highly favorable workability as compared to other metals greatly sharpens this challenge to the designer.

The review of architectural applications of aluminum on the following pages does not attempt to give a complete list of applications or available products. It attempts to indicate the potentialities, to point to available standardized products and established methods and, by showing some outstanding applications, to stimulate the imagination of designers.

In this chapter, only representative examples are shown. For variations and commercial standards, manufacturers' catalogs should be consulted.

In assembling and installing aluminum products or in the design of special application, the following suggestions will be useful: Select and specify the most suitable alloy for each particular application from the point of view of fabrication, strength and finish.

Aluminum is commercially available in a wide range of products for every architectural requirement. It can be readily formed, rolled, stamped, cast, forged or extruded. Its easy workability by common methods without special tools, along with improved fastening and welding methods, make it a material that is most versatile and economical

to fabricate as well as to erect.

Select and specify the proper gauge or dimensions for strength, durability, and the prevention of surface distortion.

Design joints and fastenings for economy, reliability and appearance. Slip and snap joints are extremely practical; mechanical fastenings are to be used only where they do not detract from appearance; for maximum strength, use welding. Provide for expansion and contraction. Alloys used for architectural work have a coefficient of thermal expansion of .000013 inch per inch per degree F.

Insulate aluminum from contact with dissimilar metals. For detailed information on physical and mechanical properties, fabrication, joining and finishing, refer to the chapters in which the particular subjects are discussed.

7.1 INDUSTRIAL ROOFING AND SIDING

Aluminum roofing and siding in general is designed for use on industrial plants, commercial and public buildings, farms and houses. Typical examples of the use of industrial roofing and siding, as differentiated from the roofing and siding for farm use, are power plants, conveyor housings, mine heads, warehouses, loading docks, armories, grandstands, hangars, bus and railroad terminals, drive-in theaters, and the like. Restaurants, super-markets, filling stations and other stores are using it for both interiors and exteriors because of its clean, modern appearance and freedom from maintenance.

Light-weight, strong, aluminum roofing and siding cut handling costs all along the line. During erection, for instance, they can be raised into position by hand, and can be lifted to working level in small quantities with a hand line, eliminating expensive hoisting equipment. A 12-foot sheet, full 48⅓ inches wide, weighs less than 28 pounds compared to weights up to 182 pounds for the same area of certain other roofing and siding materials. Aluminum sheets are easily handled by the erecting crew without costly fatigue.

In addition, these sheets are easy to cut, form, drill and punch, since they require no special equipment. As a result, work is speeded up, and scaffolding held to a minimum. Reduction of scaffolding can be especially important on maintenance work, where it means a minimum of interference with production. The use of recommended fasteners and flashings ensures further savings in installation, since they are designed for simplicity of application and possess the required structural properties.

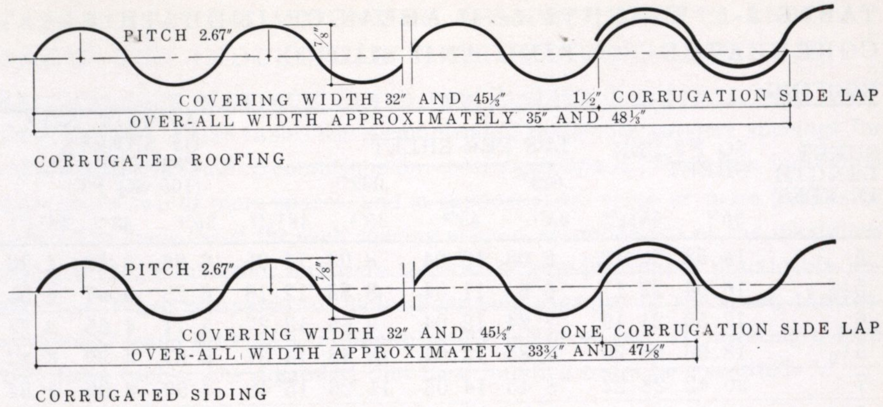


Fig. 7-1.

Sheets are available in different forms which allow considerable latitude in architectural appearance and detail. The following sections describe the various types and indicate the general uses and methods of application of the materials. The uses of these products, however, are not limited to those mentioned, and may be expanded by the designer's ingenuity.

CORRUGATED ROOFING AND SIDING FOR INDUSTRIAL APPLICATIONS: The production of corrugated sheets is described in Chapter 3. Sheets are available in thicknesses of 0.024 and 0.032-inch, in plain mill or embossed finishes, and in lengths of 5 feet to 12 feet in increments of 6 inches.

Figure 7-1 shows the cross-sectional shape, the widths and the laps normally used. As can be seen, the roofing sheets have one side turned up and one down, whereas some siding sheets have both sides turned in the same direction.

Sheets can be curved across the width of the sheet so that the ridges and valleys form an arc, with a tolerance of ±1 inch measured across the chord. The minimum radius for such bends is 18 inches.

TABLE 7-1: WEIGHTS AND AREAS OF INDUSTRIAL CORRUGATED ROOFING AND SIDING

ROOFING

SHEET LENGTH IN FEET	SQ FT PER SHEET		LBS PER SHEET				APPROX. NO.* OF SHEETS PER SQUARE (100 SQ FT)		
			.024"[1]		.032"[1]				
	35"[2]	48⅓"[2]	35"[2]	43"[2]	35"[2]	48⅓"[2]	35"[2]	43"[2]	48⅓"[2]
5	14.58	20.16	6.03	10.04	8.04	11.05	6.86	5.58	4.96
5½	16.04	22.17	6.64	11.04	8.85	12.16	6.23	5.07	4.51
6	17.50	24.19	7.24	12.04	9.65	13.27	5.71	4.65	4.13
6½	18.96	26.20	7.84	13.04	10.46	14.37	5.27	4.29	3.82
7	20.42	28.22	8.45	14.05	11.26	15.48	4.90	3.99	3.54
7½	21.88	30.23	9.05	15.05	12.07	16.58	4.57	3.72	3.31
8	23.33	32.25	9.65	16.06	12.87	17.69	4.29	3.49	3.10
8½	24.79	34.27	10.26	17.06	13.68	18.79	4.03	3.28	2.92
9	26.25	36.28	10.86	18.06	14.48	19.20	3.81	3.10	2.76
9½	27.71	38.30	11.46	19.06	15.29	21.00	3.61	2.04	2.61
10	29.17	40.31	12.07	20.06	16.09	22.11	3.43	2.79	2.48
10½	30.63	42.33	12.67	21.07	16.90	23.21	3.26	2.66	2.36
11	32.08	44.34	13.27	22.08	17.70	24.32	3.12	2.54	2.26
11½	33.54	46.36	13.88	23.08	18.51	25.43	2.98	2.43	2.16
12	35.00	48.37	14.48	24.08	19.31	26.53	2.86	2.33	2.07

* To allow for side and end laps in estimating, add 16 percent for 35-inch roofing and 11 percent for 48⅜-inch roofing; add 9 percent for 33¾-inch siding and 6 percent for 47⅛-inch siding.
[1] Sheet thickness.
[2] Sheet width.

SIDING

SHEET LENGTH IN FEET	SQ FT PER SHEET		LBS PER SHEET				APPROX. NO.* OF SHEETS PER SQUARE (100 SQ FT)	
			.024"[1]		.032"[1]			
	33¾"[2]	47⅛"[2]	33¾"[2]	47⅛"[2]	33¾"[2]	47⅛"[2]	33¾"[2]	47⅛"[2]
5	14.06	19.64	5.82	8.06	7.76	10.75	7.11	5.09
5½	15.47	21.60	6.40	8.87	8.54	11.82	6.46	4.63
6	16.87	23.56	6.99	9.67	9.31	12.90	5.93	4.24
6½	18.28	25.53	7.57	10.48	10.09	13.97	5.47	3.92
7	19.69	27.49	8.15	11.29	10.87	15.05	5.08	3.64
7½	21.09	29.45	8.73	12.09	11.65	16.12	4.74	3.40
8	22.50	31.42	9.31	12.90	12.42	17.20	4.44	3.18
8½	23.91	33.38	9.90	13.70	13.20	18.27	4.18	3.00
9	25.31	35.34	10.48	14.51	13.97	19.35	3.95	2.83
9½	26.72	37.31	11.06	15.32	14.75	20.42	3.74	2.68
10	28.12	39.27	11.64	16.12	15.52	21.50	3.56	2.55
10½	29.53	41.23	12.22	16.93	16.30	22.57	3.39	2.43
11	30.94	43.20	12.81	17.73	17.08	23.65	3.23	2.31
11½	32.34	45.16	13.39	18.54	17.86	24.72	3.09	2.21
12	33.75	47.13	13.97	19.35	18.63	25.80	2.96	2.12

* To allow for side and end laps in estimating, add 16 percent for 35-inch roofing and 11 percent for 48⅜-inch roofing; add 9 percent for 33¾-inch siding and 6 percent for 47⅛-inch siding.
[1] Sheet thickness.
[2] Sheet width.

However, corrugated sheets can be curved lengthwise also . . . . but to a radius of no less than 20 feet, as the edge that is downturned goes into compression and buckles when the sheet is curved to a shorter radius. Sheets may be obtained *precurved* to any radius desired, down to a minimum of 30 inches.

As indicated in Table 7-2, the strength-to-weight ratio of corrugated aluminum sheet is very high. Resulting advantages are very light loading on the structure and reduced labor for handling. A 12-foot by 4-foot sheet weighs about 27 pounds and the material can be applied rapidly, allowing the structure to be enclosed within a very short period. The finish is such that the sheets require no painting either inside or out. Aluminum roofing and siding offers an additional insulating advantage over other corrugated materials, as can be seen in Table 7-3.

From Table 7-3 it is evident that the heat loss is far less through aluminum than through any of the other materials. Even more important, note that for "Heat Flow Down" as in summer, aluminum permits less than half as much heat to enter a building. In air-conditioned buildings this is of utmost importance in reducing operating costs. Another advantage is the low first cost of aluminum which is less than any other rustproof metal.

RIBBED SIDING: Another product designed primarily for industrial use is ribbed siding shown in Figure 7-2. This sheet is available in 5-foot to 22-foot, 5-inch lengths in 6-inch increments, in thicknesses of .032, .040 and .050-inch and with or without an embossed finish. Sheet coverage is shown in Table 7-4.

Table 7-5: Lists recommended maximum support spacings for various uniform loading conditions on continuous spans (where the individual sheet spans two or more spaces, and is supported by three or more girts). The loads listed for each spacing are not an indication of the maximum strength of the material, but were selected to provide sound, practicable application. When compared to the load-carrying capacity of the sheet, the recommended loads provide a minimum safety factor of two. In selecting load and spacing from this table, it is suggested that local building codes be consulted.

ROOFING APPLICATION: When using corrugated roofing sheet, sufficient slope or roof pitch is required to obtain suitable drainage, inasmuch as weather-tightness in application is obtained by end and side lapping of the sheets (see Figure 7-3). To accomplish this, the following roof-pitch recommendations are listed. For roof slopes up to 30 feet in length, the minimum rise recommended is 3 inches per foot. For slopes over 30 feet in length, or with more than three courses of sheets, the minimum rise recommended is 4 inches per foot.

Begin application of roofing sheets with the lower course, starting at the end of the roof opposite the prevailing wind. Application may proceed across the roof one course at a time, or all courses may proceed simultaneously, each course being kept at least one sheet ahead of the next course above. Lay each sheet so that the exposed edge is turned down and the overlapped or covered edge is turned up. Lap sheets a minimum of 1½ corrugations at the sides and fasten together on 12 to 15-inch centers with No. 10 slotted-head aluminum or stainless steel sheet-metal screws (see Figure 7-4). Use ½-inch O.D. x 13/64-inch I.D. aluminum or stainless-steel-backed neoprene washers (see Figure 7-5).

Aluminum or stainless steel nuts and bolts are an acceptable substitute for sheet-metal screws. Nuts and bolts must have aluminum-backed neoprene washers. Lap ends of sheets a minimum of 6 inches, with fasteners passing through laps not less than 1 inch from the ends of the sheets. Make end laps only over supports. Continue application up to ridge on both roof slopes, and finish with formed ridge roll. Fasten apron of ridge roll to crown of every fourth corrugation, using No. 10 sheet-metal screws with washers. Molded neoprene closure strips may be used under aprons of ridge roll if desired.

FLASHING AND CLOSURES: Use formed aluminum flashing sections at junctures of roofs and side walls or end walls, around openings, and the like. Molded neoprene or preformed contoured aluminum closure strips may be used in conjunction with aluminum flashing if desired. Figure 7-6 shows typical flashing cross-sections and closure strips. For all methods of attachment other than nailing,

TABLE 7-2: RECOMMENDED SPANS, WEIGHTS AND AREAS FOR INDUSTRIAL CORRUGATED ALUMINUM

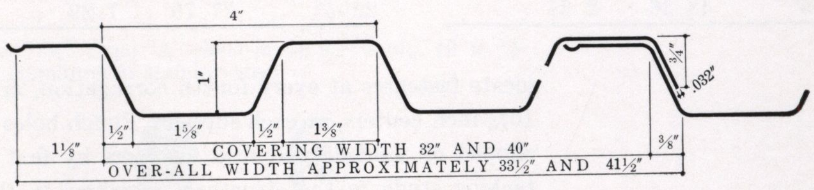
RECOMMENDED MAXIMUM SPANS FOR VARIOUS LOADINGS FOR .032" THICKNESS: These tables list recommended maximum support spacings for various uniform loading conditions on continuous spans (where the individual sheet spans two or more spaces, and is supported by three or more purlins or girts). The loads listed for each spacing are not an indication of the maximum strength of the material, but were selected to provide sound, practicable application. When compared to the load-carrying capacity of the sheet, the recommended loads provide a minimum safety factor of two. In selecting a load from these tables, it is suggested that local building codes be consulted.

ROOFING SPANS		SIDING SPANS		
UNIFORM LOAD POUNDS PER SQ FT	PURLIN SPACING INCHES	UNIFORM LOAD POUNDS PER SQ FT	GIRT SPACING INCHES	EQUIV. WIND VEL. MILES PER HOUR
20	72	10	72	50
25	72	15	72	61
30	72	20	72	71
35	69	25	72	79
40	66	30	72	87
45	63	35	69	93
50	60	40	66	100

WEIGHTS* AND AREAS*

SHEET LENGTH IN FEET	WEIGHT PER SQUARE FOOT IN POUNDS	SQUARE FEET PER SHEET	POUNDS PER SHEET	NUMBER OF SHEETS PER SQUARE OF CORRUGATION
5	.560	20.14	11.28	4.97
6	.560	24.17	13.53	4.14
7	.560	28.19	15.79	3.55
8	.560	32.22	18.04	3.10
9	.560	36.25	20.30	2.76
10	.560	40.28	22.56	2.48
11	.560	44.31	24.81	2.26
12	.560	48.33	27.07	2.07

* This table is for 48⅓-inch wide sheet.



RIBBED SIDING

Figure 7-2: Ribbed siding.

TABLE 7-3: HEAT LOSSES THROUGH CORRUGATED ALUMINUM SHEET AND OTHER MATERIALS

MATERIAL	VERTICAL SURFACE	HORIZONTAL SURFACE HEAT FLOW UP	HORIZONTAL SURFACE HEAT FLOW DOWN
Corrugated Asbestos Cement	1.13	1.30	0.92
Corrugated Steel	1.28	1.47	1.00
0.032″ Industrial Corrugated Aluminum	0.65	0.95	0.41

Values in Btu per hr per sq ft per degree F

TABLE 7-4: SHEET COVERAGE FOR 41⅝-INCH WIDE RIBBED ALUMINUM SHEET WEIGHING APPROXIMATELY 59 POUNDS PER 100 SQUARE FEET (.032-INCH)

SHEET LENGTH FEET	SQUARE FEET PER SHEET	NO. OF SHEETS PER SQUARE (100 SQ FT)	SHEET LENGTH FEET	SQUARE FEET PER SHEET	NO. OF SHEETS PER SQUARE (100 SQ FT)
5	17.34	5.77	13′-0″	45.09	2.22
5½	19.08	5.24	13′-6″	46.83	2.14
6	20.81	4.81	14′-0″	48.56	2.06
6½	22.55	4.43	14′-6″	50.30	1.99
7	24.28	4.12	15′-0″	52.03	1.92
7½	26.02	3.84	15′-6″	53.77	1.86
8	27.75	3.60	16′-0″	55.50	1.80
8½	29.48	3.39	16′-6″	57.23	1.75
9	31.22	3.20	17′-0″	58.97	1.70
9½	32.95	3.03	17′-6″	60.70	1.65
10	34.69	2.88	18′-0″	62.44	1.60
10½	36.42	2.75	19′-0″	65.91	1.52
11	38.16	2.62	20′-0″	69.37	1.44
11½	39.89	2.51	21′-0″	72.84	1.37
12′-0″	41.63	2.40	22′-0″	76.31	1.31
12′-6″	43.36	2.31	22′-5″	77.76	1.29

locate fasteners at every fourth corrugation, or on 10⅔-inch centers, at each support. Punch holes for clipped or welded type stud fasteners by first attaching studs to the structural members in their proper location, and then driving the sheet down over each stud with a rubber mallet. Drill or punch holes for other types of fasteners as required. Install rivet-stud type fasteners with formed aluminum washers under riveted heads of the studs against the corrugation. Locate a sheet-metal screw with neoprene washer at each sheet corner not fastened to purlins (see Figures 7-4 and 7-5).

When roofing is attached to metal structures by means of self-tapping screws (see Figure 7-7), make attachments only in the valleys of the corrugations. If roofing sheet and purlins are drilled at the same time, use a No. 1 (.228-inch diameter) split-point drill. If they are drilled separately, drill .228-inch diameter through the girt and ¼-inch (.250-inch) diameter through the corrugated sheets. Draw fasteners up to a snug fit.

For all other types of fastening, place holes for fasteners only in the crowns of the corrugations (see Figures 7-8 and 7-10).

When nails are used for attaching corrugated roofing to wood purlins, maximum purlin spacing is 3 feet. Nail the roofing sheets to purlins at every third corrugation, or on 8-inch centers, beginning at the side lap on each sheet. Use a ½-inch O.D. x 13⁄64-inch I.D. aluminum or stainless-steel-backed neoprene washer under the head of each nail. Use a minimum of 50 aluminum nails and washers per square of roofing. The smallest size aluminum nail used is 9 gauge, .150-inch diameter spiral shank, 2½-inch length. Nail must penetrate sound wood at least 1½ inches (see Figure 7-10).

For applying roofing over solid deck, or over closely spaced deck boards, use aluminum nails with neoprene washers attached. Apply one layer of 15-pound felt over solid decks before applying roofing. Nail in horizontal rows at every third corrugation, or on 8-inch centers, spacing the rows of nails not more than 20 inches apart. Use a minimum of 85 nails and washers per square of roofing. Drive nails only until washers are held snugly against the corrugation. Do not deform the roof sheet by overdriving nails.

SIDING APPLICATION: For siding, begin application at the end of the building opposite the prevailing wind. Proceed in horizontal courses, beginning with the lowest course. Use molded neoprene or contoured aluminum closure strips to close the

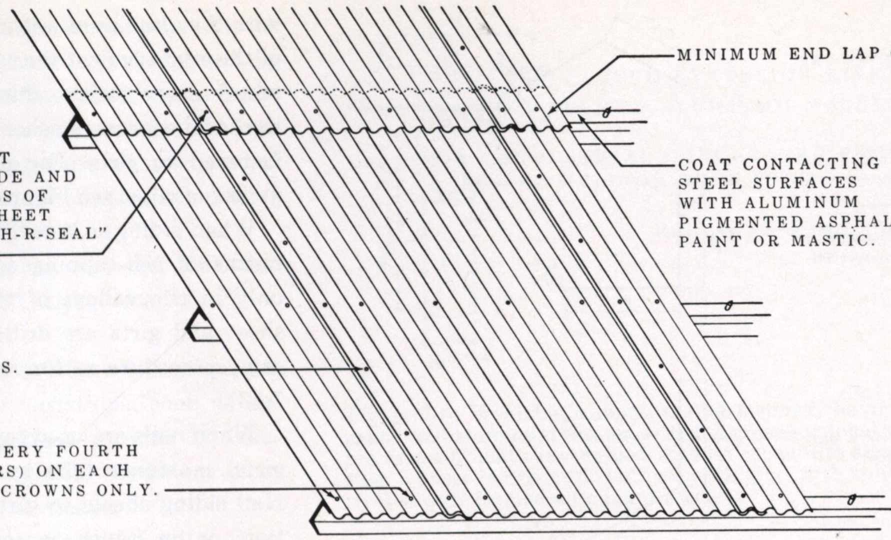


Figure 7-3: Roofing application of aluminum industrial corrugated sheets on steel frame.

TABLE 7-5: RECOMMENDED MAXIMUM SPANS FOR VARIOUS LOADINGS, RIBBED SIDING

.032-INCH THICK

UNIFORM LOAD POUNDS PER SQ FT	GIRT SPACING, CENTER TO CENTER INCHES	EQUIV. WIND VEL. MILES PER HOUR
30	78	87
35	69	93
40	65	100
45	63	106
50	61	110
55	59	117
60	57	123

bottom of the lower course of siding sheets (see Figure 7-6). Apply each siding sheet so that the exposed edge is turned in toward the building. Keep the horizontal and vertical lines of the sheet straight, plumb and true to line. Lap the sheets 1½ corrugations at the sides and fasten together as for roofing. Lap ends of sheets a minimum of 4 inches. Make end laps only over supports.

Continue application up to top of wall, finishing at eaves with formed eaves closures, fastening closure to both roofing and siding at every fourth corrugation, using No. 10 aluminum or stainless steel sheet-metal screws with aluminum or stainless-steel-backed neoprene washers (see Figures 7-4 and 7-5).

For all methods of attachment other than nailing, locate fasteners at every fourth corrugation, or on 10⅔-inch centers, at each girt. Punch holes for rivet-stud type fasteners as described above for roofing. Drill or punch holes for other types of fasteners as required. Install rivet-stud type fasteners

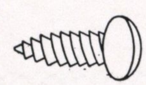


Figure 7-4: Type "A" sheet-metal screw No. 10 × ⅝-inch aluminum or stainless steel.

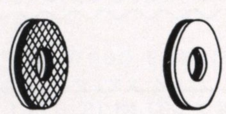


Figure 7-5: "Weath-R-Seal" type washer ½-inch OD × 13/64-inch ID aluminum-backed neoprene. Use with nail or sheet-metal screw.

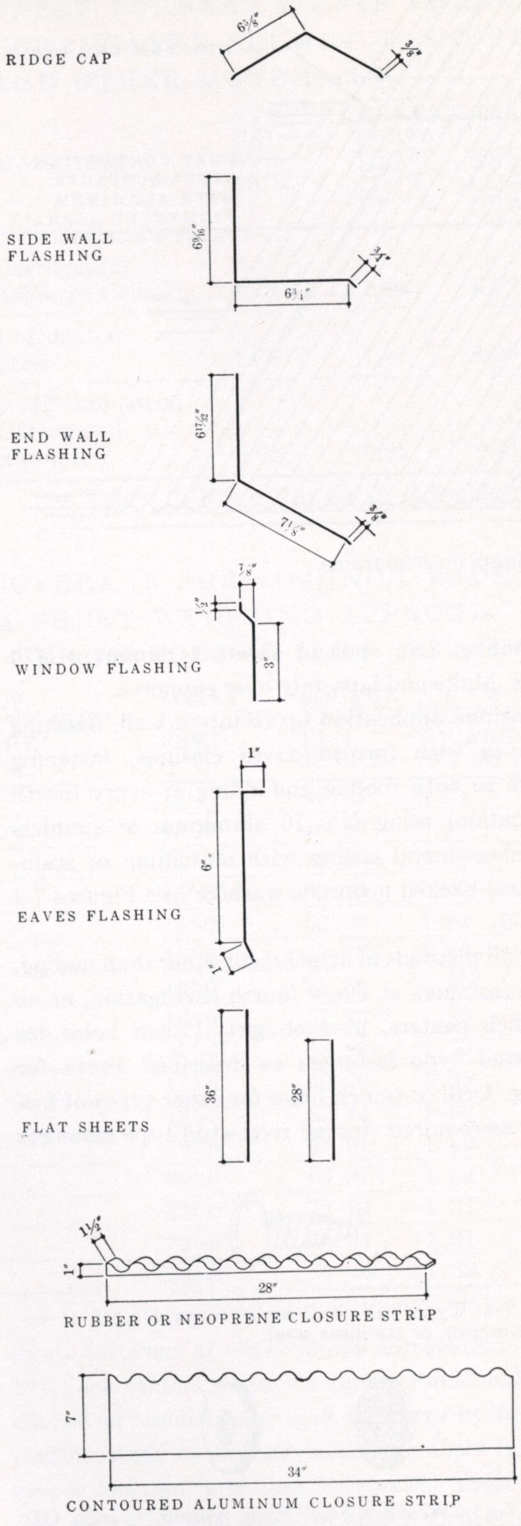


Figure 7-6: Typical flashing accessories for corrugated industrial roofing and siding.

with the aluminum washers under the riveted heads of the studs against the corrugation. Locate a sheet-metal screw with aluminum or stainless-steel-backed neoprene washer at each sheet corner not fastened to girts. For method of attachment by means of clips, see Figure 7-12.

When siding is attached to metal structures by means of self-tapping screws, make attachments only in the valleys of the corrugations. If siding sheet and girts are drilled at the same time, the same procedure as for roofing is used (see Figure 7-13).

When nails are used for attaching siding to wood girts, maximum girt spacing is 3 feet 6 inches. Nail siding sheets to girts at every third corrugation, or on 8-inch centers and nail all side laps. Use aluminum or stainless-steel-backed neoprene washer under the head of each nail. Use a minimum

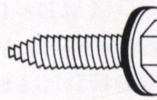


Figure 7-7: "Topseal" Type "Z" self-tapping screw. Stainless steel hex head, No. 14 x ¾-inch with "Weath-R-Seal" washer.

of 45 aluminum nails and washers per square of siding. The smallest size aluminum nail to be used is .150-inch diameter, spiral shank, 2½-inch length. Nail must penetrate sound wood at least 1½ inches (see Figure 7-10).

For applying siding over solid or closely spaced sheathing, use aluminum nails with neoprene washers attached. Nail in horizontal rows at every third corrugation, or on 8-inch centers, spacing the rows of nails not more than 24 inches apart. Use a minimum of 75 nails and washers per square of siding. Drive nails only until washers are held snugly against the corrugation. Apply one layer of 15-pound felt over solid sheathing before applying siding.

Flashing and Closures: Use formed aluminum flashing at window and door openings. Molded neoprene or contoured aluminum closure strips (see Figure 7-6) may be used in conjunction with aluminum flashing if desired.

Corner flashing may be made from flat aluminum sheet or, if preferred, corners may be closed by bending the corrugated siding sheet around the corners. When using this method, continue the direction of bend of the corrugation; do not attempt to reverse the bend. Typical details for both roofing and siding are shown in Figure 7-14.

Figure 7-15 shows a typical ribbed installation that is similar to corrugated siding details.

SPECIAL INSTALLATIONS: The applications described are typical. Many variations, such as applying siding with corrugations running horizontally, can be used to meet special conditions or to achieve desired architectural effects.

Aluminum sheets can be combined with other materials, such as translucent sheets, or used to make insulated sandwich panels as will be shown in the following sections; perforated sheet is also available.

PERFORATED CORRUGATED SHEET: The corrugated industrial siding 33¾-inch wide is available in a .024-inch thick perforated sheet. The same fasteners as shown previously can be used for this perforated sheet for assembly in installations where an acoustical surface is desired on ceilings or walls. It should be used with sound-absorbing materials made from mineral or vegetable fibers. The perforated sheet can be used as the inside sheet on the insulated sandwich wall adding acoustical qualities to the insulating value. This sheet has a stucco finish and is available in three standard lengths: 5 feet 11⅝ inches, 7 feet 11⅝ inches and 12 feet.

An outstanding application for corrugated perforated aluminum sheet is the special acoustical paneling developed for interior areas where production operations produce high noise levels. This treatment consists of a layer of glass fiber fastened to the side walls and covered with .024-inch thick perforated corrugated sheets.

On a typical job, paneling should be started about 4 feet above the floor beyond range of possible damage from material handling and similar equipment. Wood furring strips may then be nailed to the concrete blocks in order to space and support

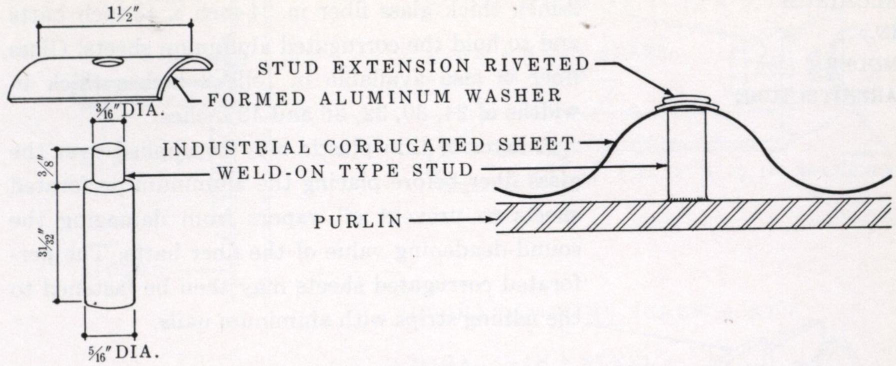


Figure 7-8: Weldable composite stud fastener, having a steel base with an aluminum shank and aluminum washer, left, and cross-sectional view of its application, right. Studs are first automatically welded with an arc gun to structural member in proper location, then a sheet is driven down over each stud with rubber mallet. Stud extension is then riveted over formed aluminum washer.

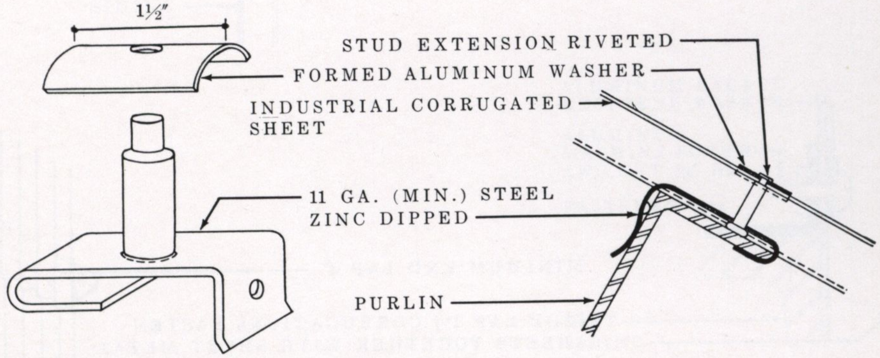


Figure 7-9: "Top-Side" Type A clip with formed aluminum washer, left, and, right, cross-sectional view of its application by fastening it to angle or channel. Method of application is same as for unit in Figure 7-8.

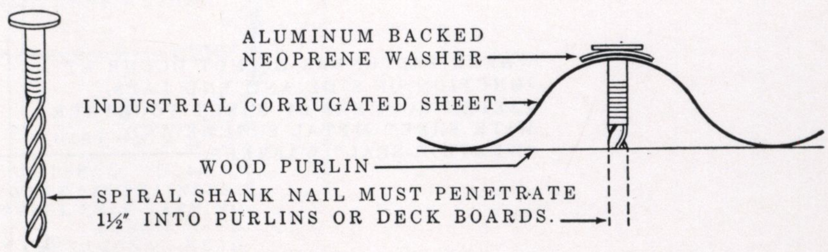


Figure 7-10: Spiral-shank aluminum roofing nail, left, and its application with aluminum-backed neoprene washer, right.

2-inch thick glass fiber in 24-inch x 48-inch batts and to hold the corrugated aluminum sheets. Glass fiber is also available in rolls 2 inches thick in widths of 24, 30, 32, 36 and 48 inches.

A layer of thin plastic may be applied over the glass fiber before placing the aluminum perforated sheets to prevent oil vapors from damaging the sound-deadening value of the fiber batts. The perforated corrugated sheets may then be fastened to the nailing strips with aluminum nails.

TRANSLUCENT CORRUGATED SHEET APPLICATION: Lighting problems are greatly simplified by the use of corrugated plastic sheets. These are available from several sources and in a variety of colors, and are corrugated to interfit with the corrugated aluminum sheets of roofing or siding. The plastic sheets can be alternated with aluminum sheets, or installed in continuous courses, depending on the interior lighting requirements.

Spacing of purlins and girts for application of corrugated plastic panels should be in accordance with recommendations of the manufacturer of such panels.

Attach corrugated plastic panels by any of the methods listed for aluminum corrugated sheets.

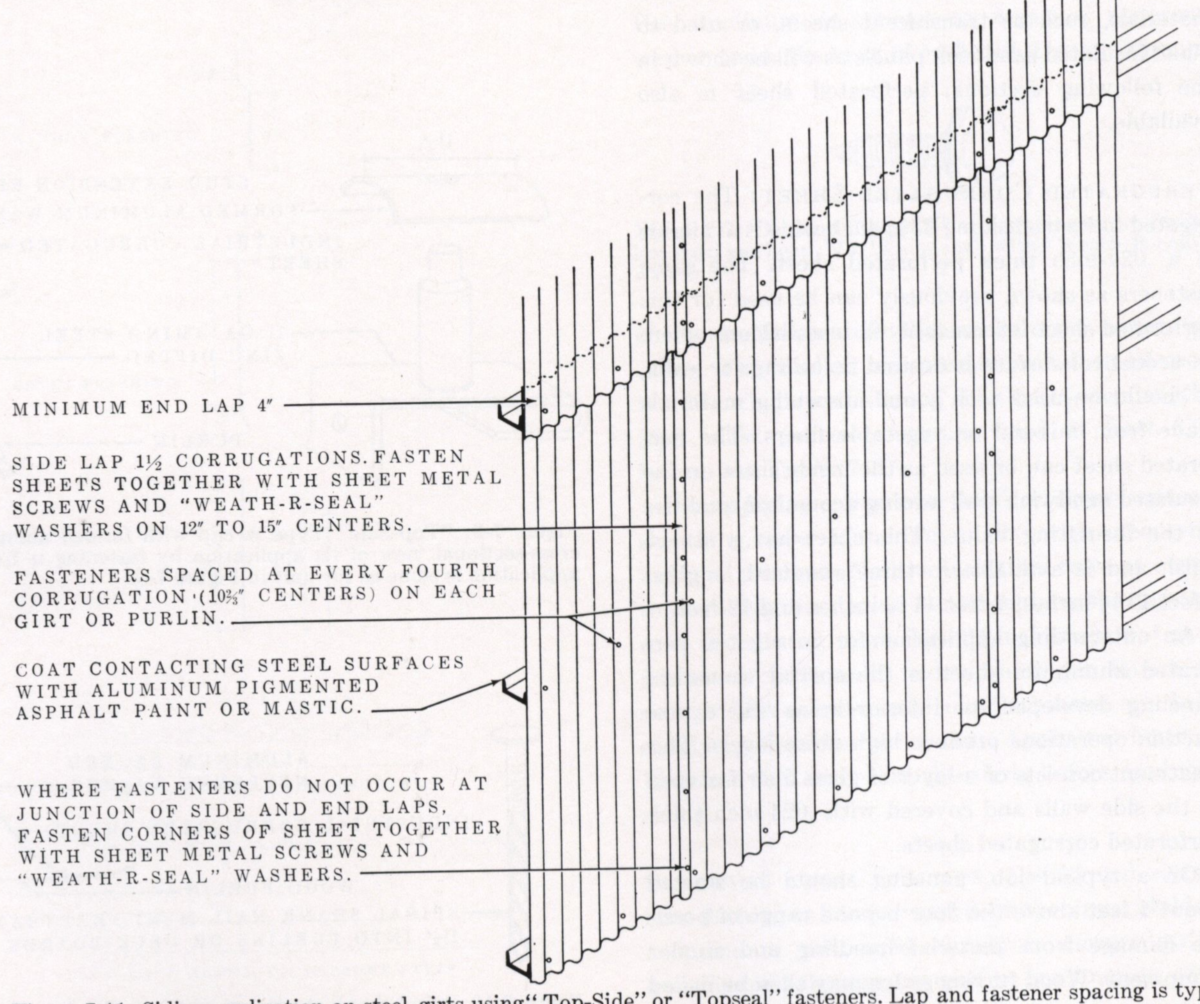


Figure 7-11: Siding application on steel girts using "Top-Side" or "Topseal" fasteners. Lap and fastener spacing is typical for rivet-stud fasteners.

Drill rather than punch attachment holes in the plastic. Space fasteners on 8-inch maximum centers along each girt or purlin. Side-lap, fastener and end-lap requirements are the same for corrugated plastic as for corrugated aluminum.

INSULATED CORRUGATED SANDWICH SIDING: If insulation in the wall is desired, two industrial corrugated sheets with an insulating material such as glass wool or mineral wool between them may be installed. Maximum girt spacing for this type installation is 36 inches.

Apply the first or inner sheet directly to the building structure. If structure is of metal, use No. 14 stainless steel self-tapping screws, spacing fasteners at every third corrugation (8-inch centers) at each girt. When attaching to a wooden structure, nail the sheet to each girt at every other corrugation ($5\frac{1}{3}$-inch centers). All attachments for the inner sheets should be in the valleys of the corrugation. Allow $1\frac{1}{2}$ corrugations for side laps and make end laps 4-inch minimum, with end laps occurring only over girts (see Figure 7-16).

Spacing members for the inner and outer corrugated sheets consist of formed aluminum "U" and "Z"-shaped sections. These are formed in the field from aluminum sheet, 3003-H14 alloy, .060-inch thick (Figure 7-17).

Attach the "U" sections along top and bottom of the corrugated sheets, and attach the "Z" sections to the corrugated sheets between and parallel to the "U" sections, using No. 10 x $\frac{5}{8}$-inch aluminum or stainless steel sheet-metal screws. Space these members to correspond to the dimensions of the insulation panel to be used. Place the insulation in position and attach the outer corrugated panels to the spacing members, using No. 10 x $\frac{5}{8}$-inch aluminum sheet-metal screws, placed in the corrugation valleys and spaced at every third corrugation (8-inch centers). Install an aluminum-backed neoprene washer under the head of each exposed sheet-metal screw. Side lap the sheets $1\frac{1}{2}$ corrugations, fastening side laps on 12 to 15-inch centers, using No. 10 x $\frac{5}{8}$-inch aluminum sheet-metal screws with an aluminum-backed neoprene washer under the head of each screw. End lap the sheets a mini-

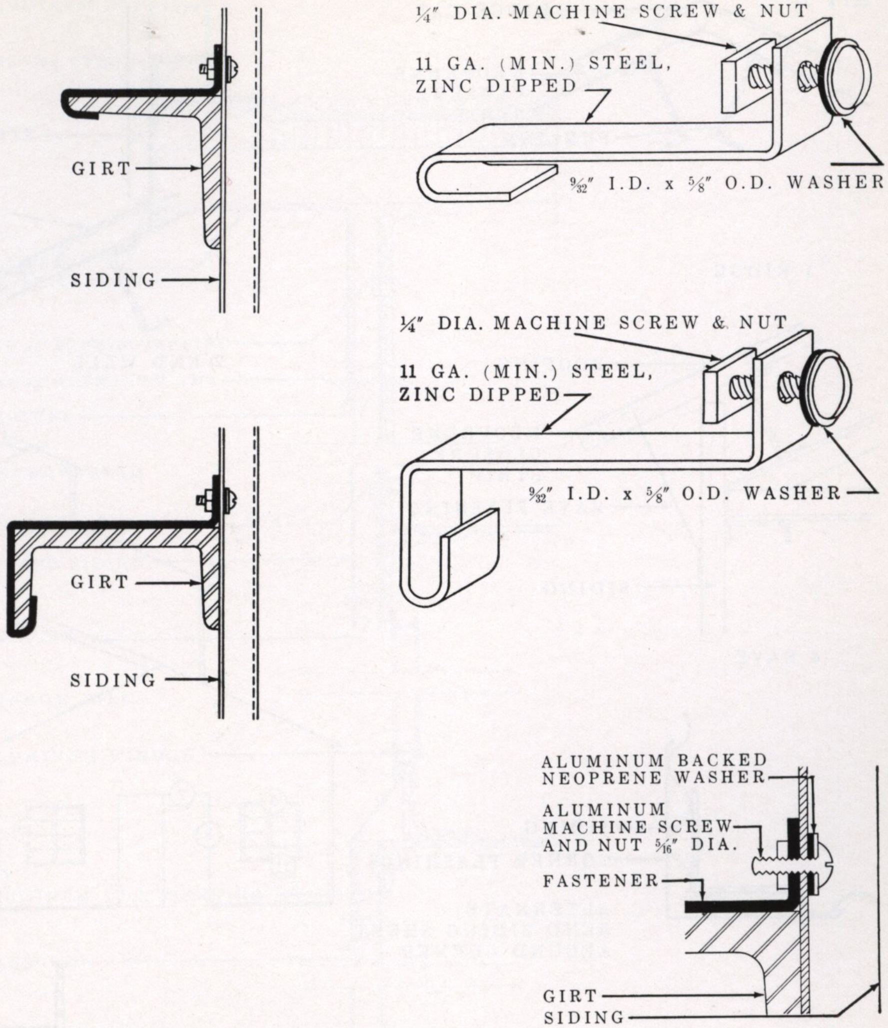


Figure 7-12: Clips for attaching aluminum siding.

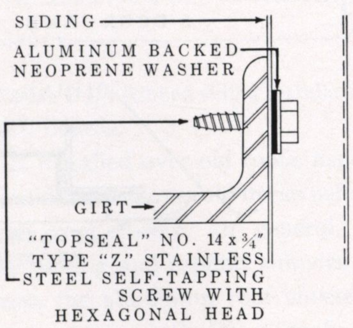


Figure 7-13: Self-tapping screw attachment.

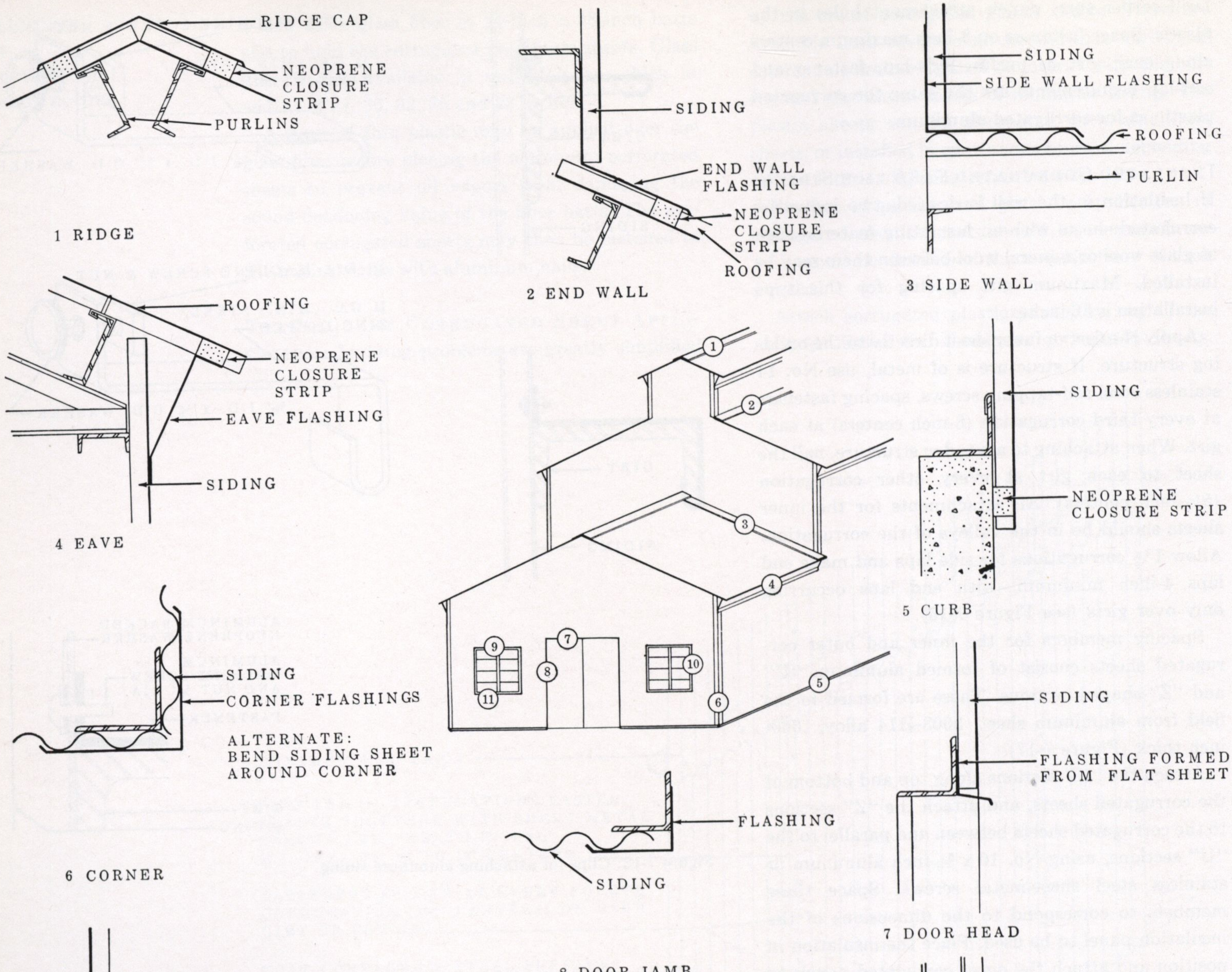


Figure 7-14: Typical flashing details.

mum of 4 inches, with end laps occurring only over spacing members (Figure 7-16).

Form flashing for doors, windows and corners from flat aluminum sheet.

7.2 ROOFING AND SIDING FOR FARM USE, STANDARD CORRUGATED AND 5V-CRIMP

This material has the same advantages as industrial roofing and siding. As progressive farmers realize the harmful effects of heat on the health and production of farm animals, the use of aluminum roofing and siding increases. This material reflects up to 95 percent of all radiant heat and keeps interiors up to 15 degrees cooler in summer.

An added advantage is that pure rainwater can be collected, for aluminum is non-toxic.

Farm roofing and siding sheets are available in two thicknesses: .024 and .019-inch. Standard lengths are 6, 7, 8, 9, 10, 11 and 12 feet.

The three types available are 1¼-inch, 2½-inch corrugated and 5V-Crimp. All of these sheets are available in a smooth mill or stipple embossed finish. (See Figure 7-18)

ROOF APPLICATION: Sheets are applied over closed or spaced roof boards, with the opening between boards not to exceed 6 inches. A typical roof deck is 1-inch x 6-inch board laid on 12-inch centers. While 5-V Crimp sheets and 1¼ x 1¼ x .019-inch corrugated sheets are applied only over solid roof sheathing, the other corrugated sheets can be applied over purlins. The spacing of purlins is governed by the loading and the sheet used (see Table 7-6).

The minimum roof pitch for single-course roofs is 3 inches per foot. For roofs having two courses up to 20 feet in length of slope, the minimum roof pitch is 4 inches per foot. For roofs having more than two courses and for roofs over 20 feet in length of slope, the minimum roof pitch is 5 inches per foot.

Apply a single layer of asphalt-saturated felt, 15-pound weight or heavier, using aluminum felt paper nails, over roof deck before applying aluminum roof sheets. Lay the felt in horizontal courses starting at the eave and lapping the courses a minimum of 3 inches, with laps occurring over the

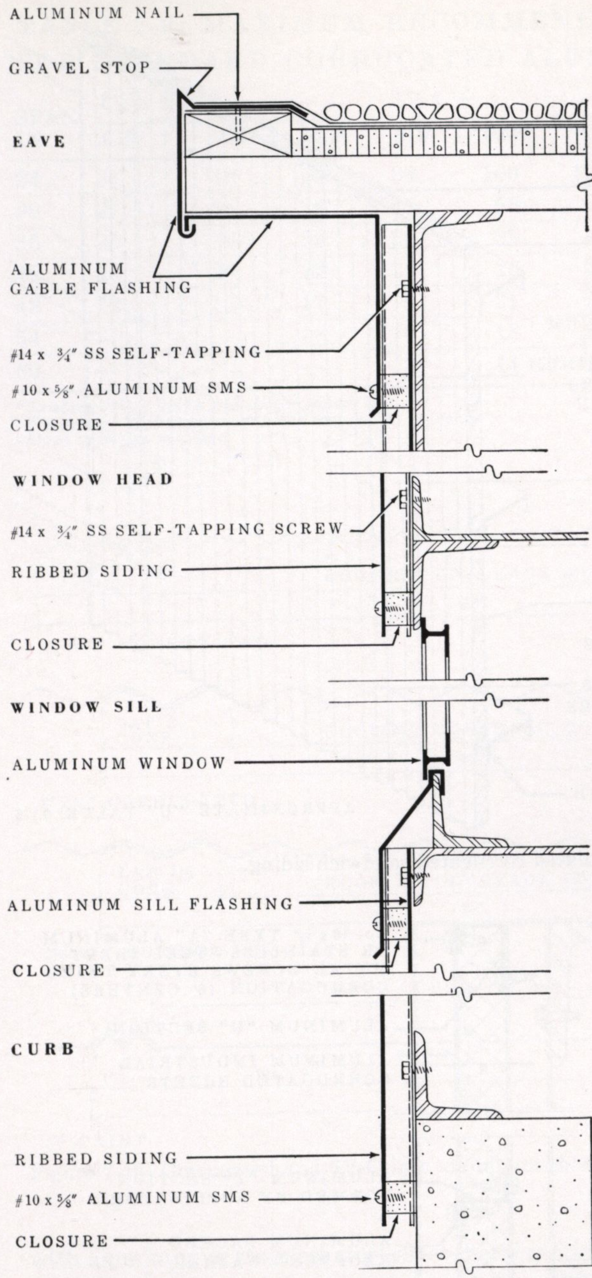


Figure 7-15: Ribbed siding installation, vertical section.

deck boards.

If installed over old roofs, asphalt-saturated felt should be used over old decks before applying aluminum roof sheets. In general, asphalt-saturated roll roofing and asphalt shingles make satisfactory bases for aluminum roof sheets if unbroken and reasonably smooth. For re-roofing an existing wood shingle roof, 2 x 4 nailers placed flat over the old

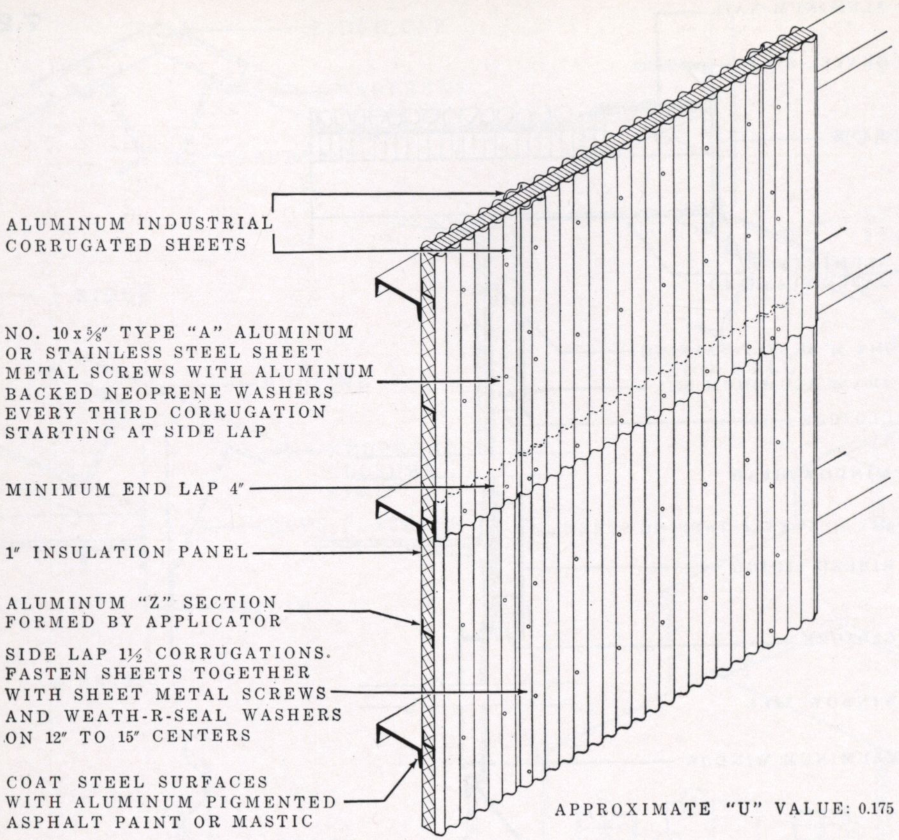


Figure 7-16: Application of insulated corrugated sandwich siding.

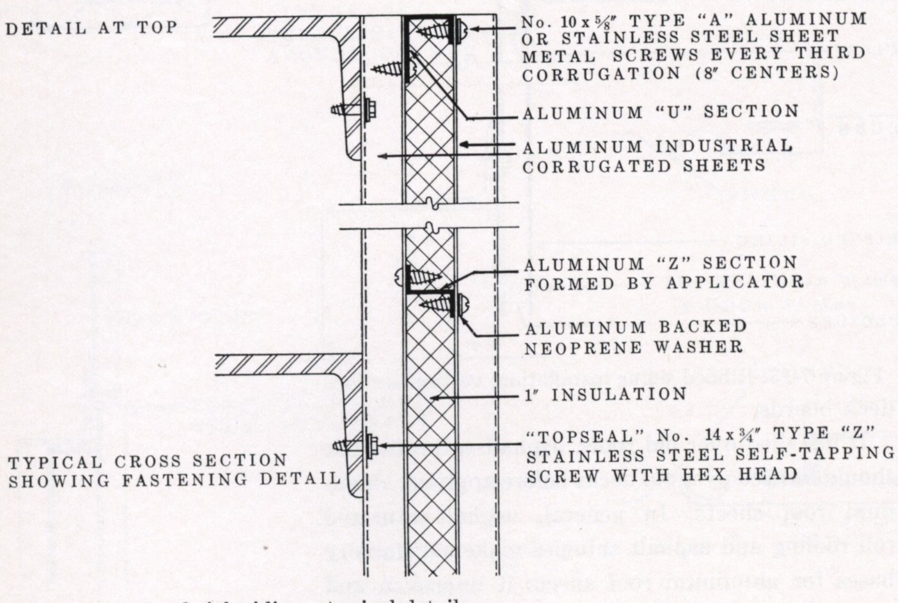


Figure 7-17: Sandwich siding—typical details.

shingles may be used. Maximum spacing of nailers should be 18 inches. Nailers should run parallel with the shingle courses, should be nailed to the building structure, and be spaced so that end laps of roof sheets occur only over nailers. Steel nail heads should be covered with aluminum pigmented mastic or asphalt-saturated felt.

Start first course of roof sheets at lower corner of roof and proceed horizontally in parallel courses and upward from eaves to ridge. Extend lower sheets 1 to 2 inches below edge of deck to form a drip edge. Lap the $1\frac{1}{4}$-inch corrugated sheets $2\frac{1}{2}$ corrugations, lapping the sheets so that the prevailing winds blow over the laps and not into them. The $2\frac{1}{2}$-inch corrugated sheets have both edges turned down. Consequently, to obtain the necessary $1\frac{1}{2}$ corrugation side lap, every other sheet must be reversed so the edges are up. Be sure the upturned edges are covered by the edges of both adjoining sheets.

Use only spiral-shank aluminum roofing nails with neoprene sealing washers attached. Nails should be sufficiently long to penetrate the full thickness of deck boards. Nail only through crowns of corrugations. Do not overdrive nail and crush or flatten corrugation, but stop when nail head holds sealing washer snug in slight dimpling of corrugation crown.

For all types of applications of sheets other than over spaced purlins: Nail at end laps and eaves at every other corrugation on the $2\frac{1}{2}$-inch corrugated sheets, and at every third corrugation on the $1\frac{1}{4}$-inch corrugated material. Nail side laps at approximately 12-inch intervals. Equally space three nails vertically through the center of each sheet up to 8 feet long, and four nails for sheets over 8 feet long. Space three nails horizontally through the center of each sheet. Use a minimum of 100 nails per square of roofing. For improved holding qualities use spiral-shank roofing nails. For fastening corrugations to 2 x 4 purlins or nailers, use only $2\frac{1}{2}$-inch long spiral-shank aluminum roofing nails with attached neoprene sealing washers. For fastening to nailers, nail at eaves and end laps as described above. At intermediate nailers, space nails at every fourth corrugation for the $2\frac{1}{2}$-inch type and at every sixth

corrugation for the 1¼-inch type. For fastening 2½-inch corrugated to 2 x 4 purlins, nail at every corrugation at eaves and end laps, and at every other corrugation at intermediate purlins.

Slight curving may be done on the job to fit roofs having a slight curvature. In such cases, each end of all sheets should be fastened with not less than four ¼-inch diameter aluminum or stainless steel bolts and nuts, using neoprene sealing washers. Use aluminum-pigmented mastic at side and end laps.

SIDING APPLICATION: Sheets may be applied over solid or spaced sheathing, with openings not to exceed 12 inches. Where siding is subjected to traffic, openings in lower 4 feet (approx.) of sheathing should not exceed 4 inches. Apply one layer of 15-pound asphalt-saturated felt over sheathing before applying siding.

Start siding at bottom of building and work in horizontal courses proceeding upward to eave or gable end. Make side laps same as for roof sheets. Make end laps by lapping upper sheets a minimum of 4 inches over lower sheets. End laps should occur only over girts. Use the same type of nails and washers as in application of roofing. Side lap the sheets a minimum of 1½ corrugations. Nail the 2½-inch corrugated at every other corrugation and the 1¼-inch corrugated at every third corrugation at tops and bottoms of sheets and at end laps. Nail side laps on approximately 12-inch centers and space one row of nails vertically in each sheet, as was done in the roofing operation.

Nailing surface for the 2½-inch corrugation may also consist of 2 x 4 girts applied flat against the structure, with a maximum spacing of 30 inches. Approximately 2 feet of the bottom of such a wall is generally composed of 2-inch pressure-treated T & G lumber, the aluminum siding overlapping the top of the PT lumber approximately 2 inches. Nail siding at every corrugation at bottom of sheets, at the laps and at tops of sheets at eaves and gables. At intermediate girts nail at every second corrugation. Use 1¾-inch long spiral-shank aluminum roofing nails with attached neoprene washers. Fasten side laps together on 12 to 15-inch centers

TABLE 7-6: MAXIMUM RECOMMENDED LOADING FOR STANDARD CORRUGATED ALUMINUM ROOFING*

SPAN	1¼ x ¼[1]			2½ x ½[1]			3 x 9/16[1]		
IN.	.019[2]	.024[2]	.027[2]	.019[2]	.024[2]	.027[2]	.019[2]	.024[2]	.027[2]
24	38	48	53	84	100	120	72	91	99
30	27	34	38	45	55	65	43	56	60
36	20	26	30	30	35	40	29	37	41
42	16	20	22	23	26	31	20	26	27
48	12	16	17	19	21	25	17	23	24
54	—	—	—	16	18	21	15	20	22
60	—	—	—	13	14	17	12	16	18

* Loading values are in pounds per square foot.
[1] Dimensions of corrugations (width and depth) in inches.
[2] Sheet thickness in inches.

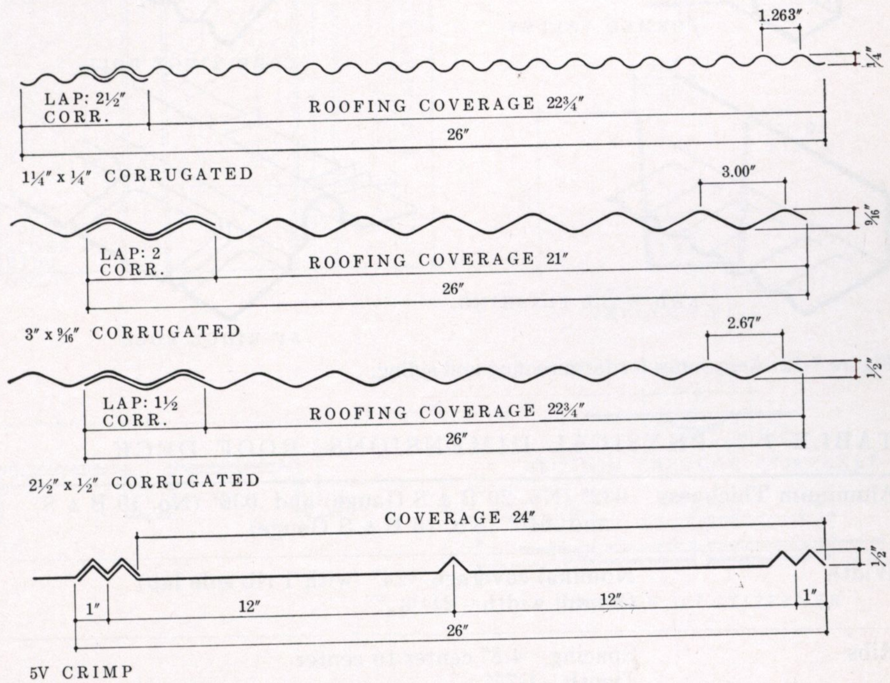


Figure 7-18: Corrugated and 5V-Crimp aluminum sheet.

with aluminum or stainless steel sheet-metal screws.

Bending: Avoid sharp ends. Allow ample radius when bending of sheet is required. Do not use sharp bending tools or shoes. Limit bends to 90 degrees and do not rebend.

Application Over Metal Structures: Methods of fastening are similar to the ones described for industrial applications. For all applications use only aluminum accessories. The available accessories are shown in Figure 7-19.

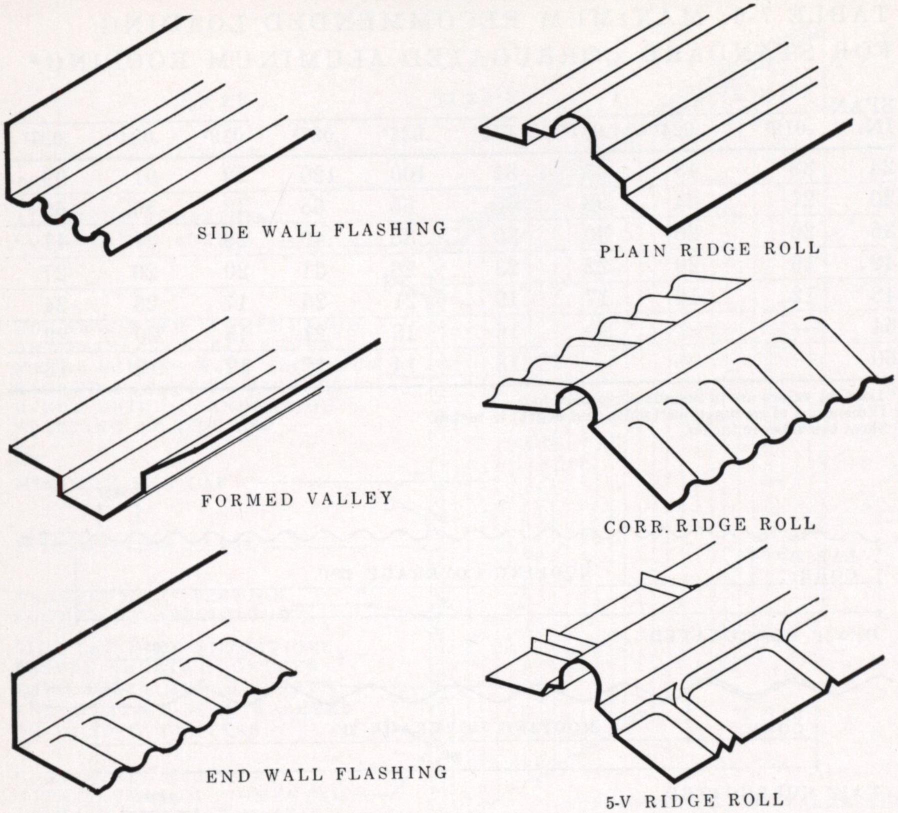


Figure 7-19: Accessories for farm roofing and siding.

TABLE 7-7: PHYSICAL DIMENSIONS, ROOF DECK

Aluminum Thickness	.032″ (No. 20 B & S Gauge) and .036″ (No. 19 B & S) and .040″ (No. 18 B & S Gauge)
Width	Nominal coverage—24″ (with 1 rib side lap) Overall width—24 13/16″
Ribs	Spacing—4.8″ center to center Depth—1.75″
Weight	.755 lb psf .032″ thickness; .851 lb psf for .036″; .945 lb psf for .040″

TABLE 7-8: LOADS AND SPANS, ROOF DECK

Sheet Thickness Inch	SPANS (MULTIPLE TYPE OF SPAN) 4′-0″	4′-6″	5′-0″	5′-6″	6′-0″	6′-6″	6′-8″
	TOTAL LOADS IN LBS PER SQ FT						
.032	93	70	56	43	—	—	—
.036	110	82	66	58	50	45	40
.040	150	112	90	74	60	50	45

Cross-Corrugated Aluminum Roll Roofing and Siding: This material is available in rolls of 50, 100 and 200 lineal feet, 28 and 48 inches wide and .019, .024 and .032-inch thick. It is made with either 1¼-inch or 2½-inch corrugations.

The rolls are easily unrolled on the surface to be covered and the matching corrugations nest to form a tight, snug-fitting covering without the need of side laps, as one roll will easily cover the full width of an ordinary building.

7.3 ROOF DECK

The aluminum roof deck in Figure 7-20 is fabricated from mill finish aluminum sheets, .032, .036 and .040-inch thick, in an alloy and temper carefully selected to offer the desired strength combined with optimum resistance to corrosion. The sheets are formed into panels having six stiffener ribs 1.75 inches deep and 4.8 inches center to center, shaped to combine economy of metal usage with good structural characteristics. The sides of the ribs are sloped to facilitate nesting of panels. Overall panel width is 24 13/16 inches, providing a nominal coverage of 24 inches when applied with a one-rib side lap as recommended. The panels are designed with provisions for a 2-inch overlap at ends. The flat surfaces between stiffener ribs are embossed on .032-inch sheets to provide added rigidity. Panels are available in lengths up to a maximum of 14 feet 5½ inches in .036 and .040 inch (see Figure 7-20)

Table 7-8 lists total loads per square foot, uniformly distributed, with corresponding support spacing. These loads are based on deflections not exceeding 1/240 of the span under live load. The loads listed will not produce a stress greater than 10,300 psi in the roof deck panels. It is suggested that local building codes be consulted when selecting a value from this table.

Installation: Begin application of roof deck at eaves in the case of pitched roofs. Application on flat roof may begin at any corner. Lap ends of panels; 2 inches with end laps occuring directly over purlins. Overlap one rib at sides of panels.

Fasten roof deck panels to building structure by means of "Rivweld" or "Topside" fasteners or No.

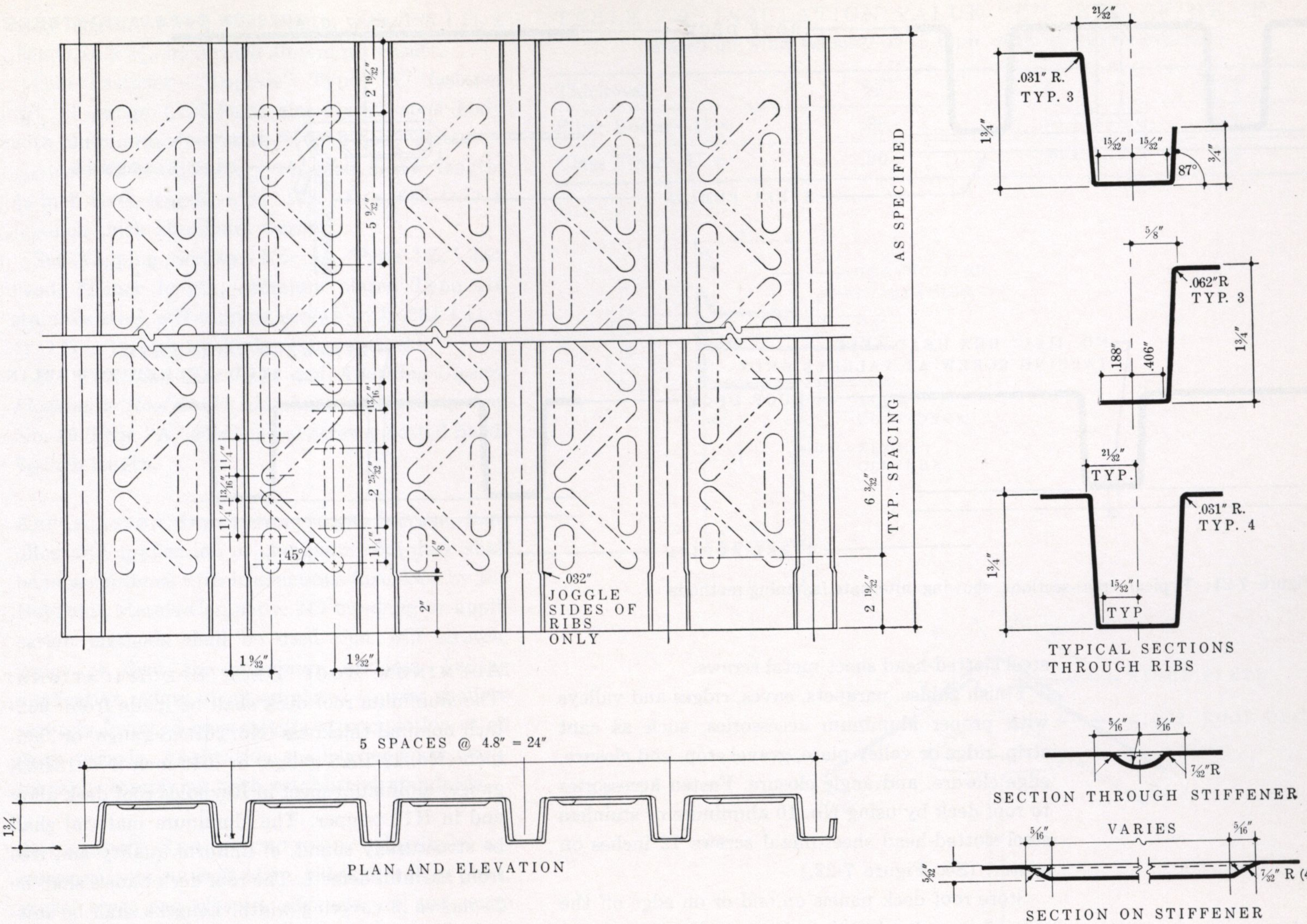


Figure 7-20: Roof deck panel details.

14 self-tapping screws. For application with "Rivweld" or "Topside" fasteners, use template for spacing fasteners. Install fasteners on top flange of purlin and place deck panel in position. Impale panel on rivet by a blow from a rubber mallet, place aluminum washer over rivet, and form head on rivet extension by upsetting with hammer. Fasten at every rib at eaves and ridge, and at every other rib at end laps and intermediate purlins.

To attach roof deck panels using No. 14 self-tapping screws, drill matching holes through bottoms of deck ribs and purlin flanges. If deck and purlin are drilled together, use a No. 1 (.228-inch diameter) splitpoint drill. If drilled separately, drill ¼-inch (.250-inch) diameter through deck and No. 1 (.228-inch diameter) through purlin. Use aluminum washers under the heads of the self-tapping screws, and draw the screws up to a snug fit. To prevent loss of alignment of holes due to creep of decking when being laid, first make an occasional fastening and then complete the fastenings (see Figure 7-21).

Fasten side laps together on approximately 24-inch centers, using No. 10 aluminum or stainless

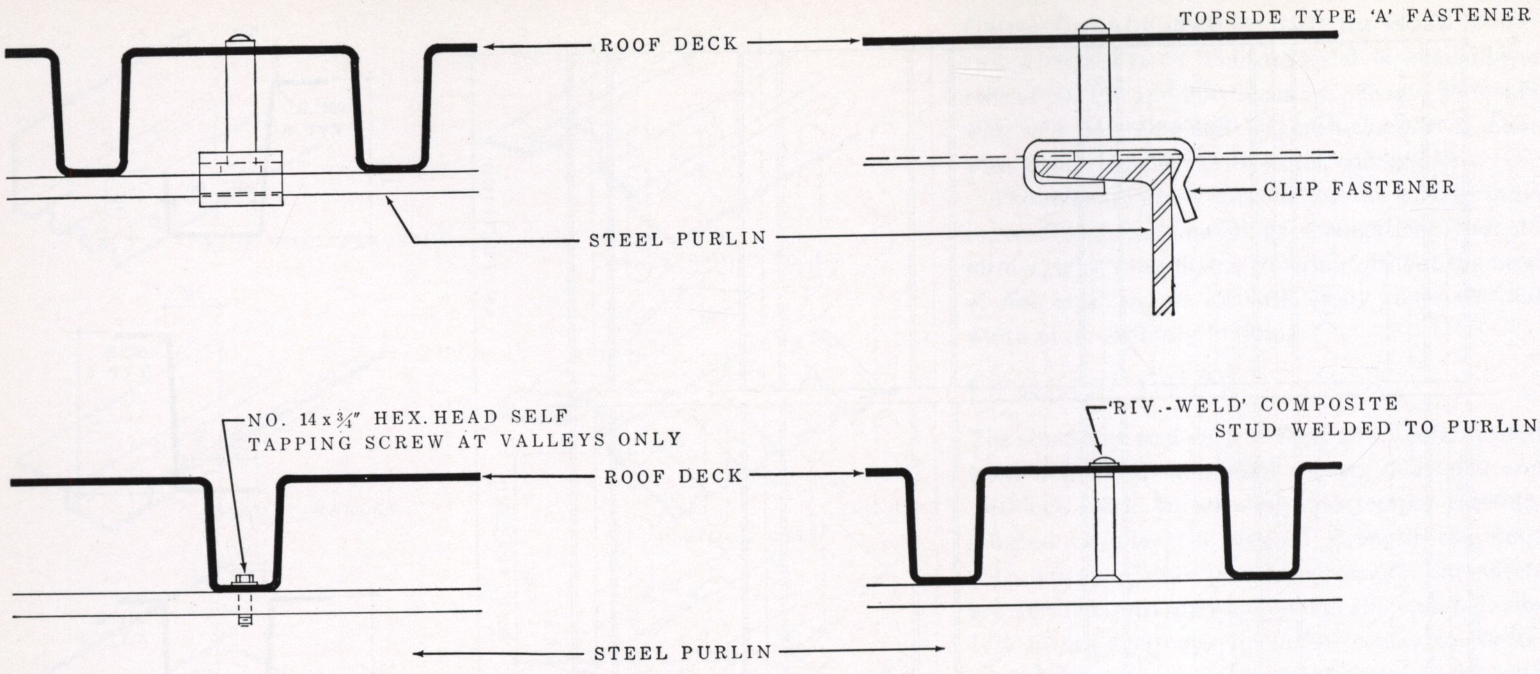


Figure 7-21: Typical cross-sections showing alternate fastening methods.

steel slotted-head sheet-metal screws.

Finish gables, parapets, eaves, ridges and valleys with proper aluminum accessories, such as cant strip, ridge or valley plate, gravel stop, end closure, edge closure, and angle closure. Fasten accessories to roof deck by using No. 10 aluminum or stainless steel slotted-head sheet-metal screws 12 inches on center. (See Figure 7-22.)

Store roof deck panels on end or on edge off the ground in a dry location. Do not allow aluminum roof deck panels to come in contact with fertilizers caustic soda, nitrate, lime, salt, acids or alkalis.

Avoid handling or application methods that will scratch, gouge or dent the aluminum surfaces. During application, securely fasten edges of uncompleted courses to structure at completion of all work periods.

Insulate the aluminum from steel supporting structure with a coating of aluminum-pigmented asphalt paint or equivalent. Insulate galvanized or steel surfaces and masonry surfaces from aluminum surfaces with aluminum-pigmented asphalt or equivalent. Avoid the use of mixed installations of copper and aluminum.

Aluminum Roof Deck Specifications: The aluminum roof deck shall be made from .032-inch nominal thickness (No. 20B&S gauge) or .036-inch (No. 19 B&S gauge) or .040-inch (No. 18B&S gauge) aluminum sheet in Reynolds roof deck alloy and in H16 temper. The aluminum material shall be structurally sound, of uniform quality and free from harmful defects. The roof deck panels shall be 24 inches in covering width. Lengths shall be suitable for the support spacing but shall not exceed 22 feet 5 inches. The main ribs shall be $1\frac{3}{4}$-inch deep, spaced 4.8-inch on centers, with provision for 2-inch overlap at ends. The flat surface between stiffener ribs shall be embossed to provide added rigidity where required. Roof deck shall be fabricated by acceptable methods to specifications and tolerances established by Reynolds Metals Company.

Fastener Specifications: Fasteners shall be of standard style and quality of any of the types listed herein:

For Attaching Deck Purlins: Welded Stud—"Riv-weld" composite stud, $\frac{5}{16}$-inch diameter steel body, $\frac{3}{16}$-inch diameter aluminum rivet, $1\frac{27}{32}$-inch

body length, ⅜-inch rivet length, with .198 I.D. x .688 O.D. x 1/16-inch thick aluminum washer.

Clip Fastener—"Topside" Type "A" fastener No. 11 gauge (.125-inch) zinc-dipped steel body with aluminum rivet stud, ⅜-inch body diameter, 3/16-inch rivet diameter, 1¾-inch body length, ⅜-inch rivet length, with .198 I.D. x .688 O.D. x 1/16-inch thick aluminum washer.

Self-Tapping Screws—No. 14, Type "Z," hex head, ¾-inch length, cadmium plated Type 410 stainless steel, self-tapping screws with .264 I.D. x ⅝ O.D. x 1/16inch thick aluminum washers.

For Fastening Side Laps and Attaching Closure Flashing to Roof Deck: Aluminum or stainless steel No. 10 Type "A" sheet-metal screws, slotted head, ⅝-inch length.

APPLICATION SPECIFICATIONS: Storage, handling and application of aluminum roof deck shall be in accordance with instructions furnished by the Reynolds Metals Company. No handling or application methods shall be used that will scratch, gouge or dent the aluminum surfaces. During application, edges of uncompleted courses shall be securely fastened to structure at completion of all work periods. Application shall be of good workmanship complying with established standards.

ACCESSORY SPECIFICATIONS: Aluminum accessories, such as cant strip, ridge or valley plate, gravel stop, end closure, edge closure and angle closure shall be of 1100 or 3003 alloy or equivalent aluminum material of .032-inch minimum thickness (No. 20 B&S gauge). Application of aluminum accessories shall be in compliance with general contractor's specifications.

GENERAL SPECIFICATIONS: The aluminum shall be insulated from steel supporting structure with a coating of aluminum-pigmented asphalt paint or equivalent. Galvanized or steel surfaces and masonry surfaces shall be insulated from aluminum surfaces with aluminum pigmented asphalt coating or equivalent. Mixed installations of copper and aluminum shall not be used. The roof deck panels shall be kept dry prior to application

TABLE 7-9: INSULATION VALUE "U"—BTU/SF/HR/°F
(Based on wind velocity of 15 mph, with underside exposed)

Thickness	½"	1"	1½"
Fiber Board—U =	.36	.23	.17
Glass Fiber—U =	.30	.19	.14

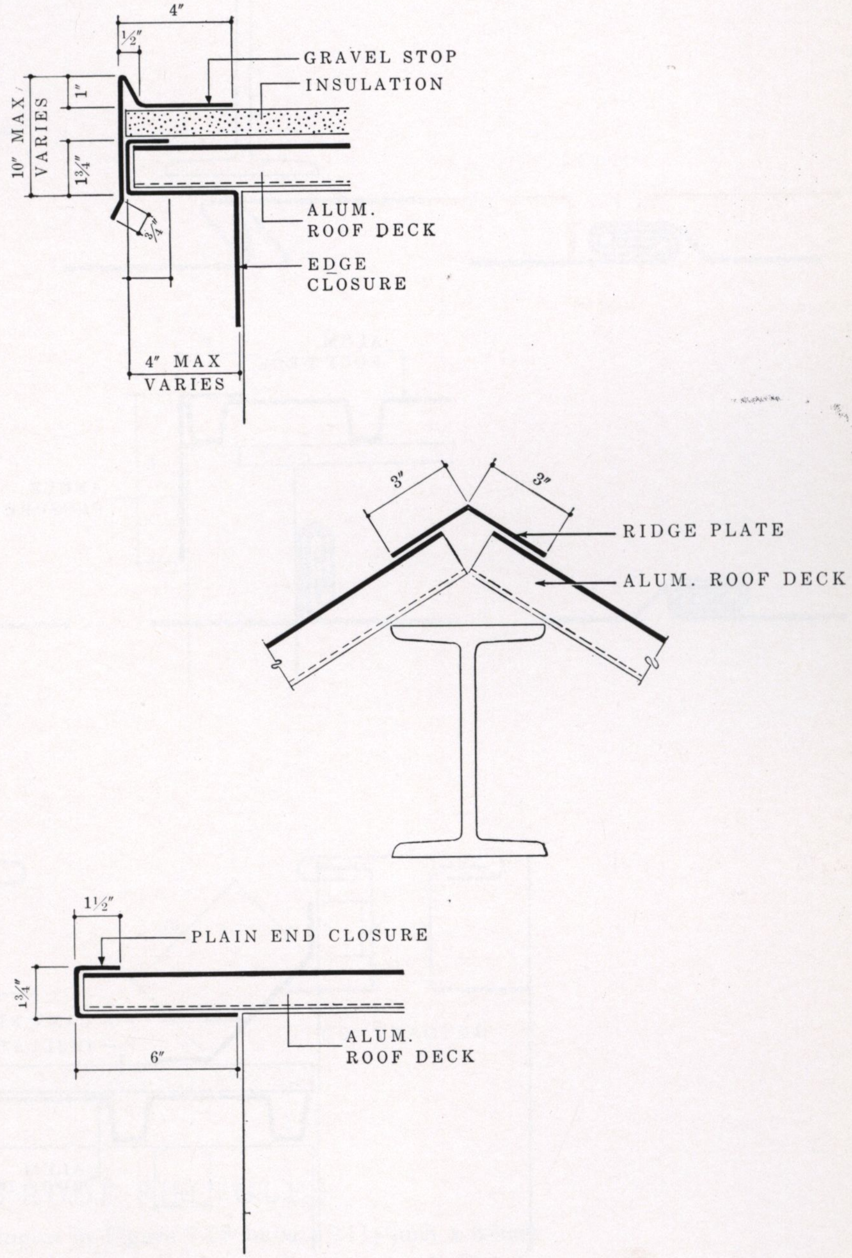


Figure 7-22: Typical flashing accessories used in application of aluminum roof deck. Concluded on page 200.

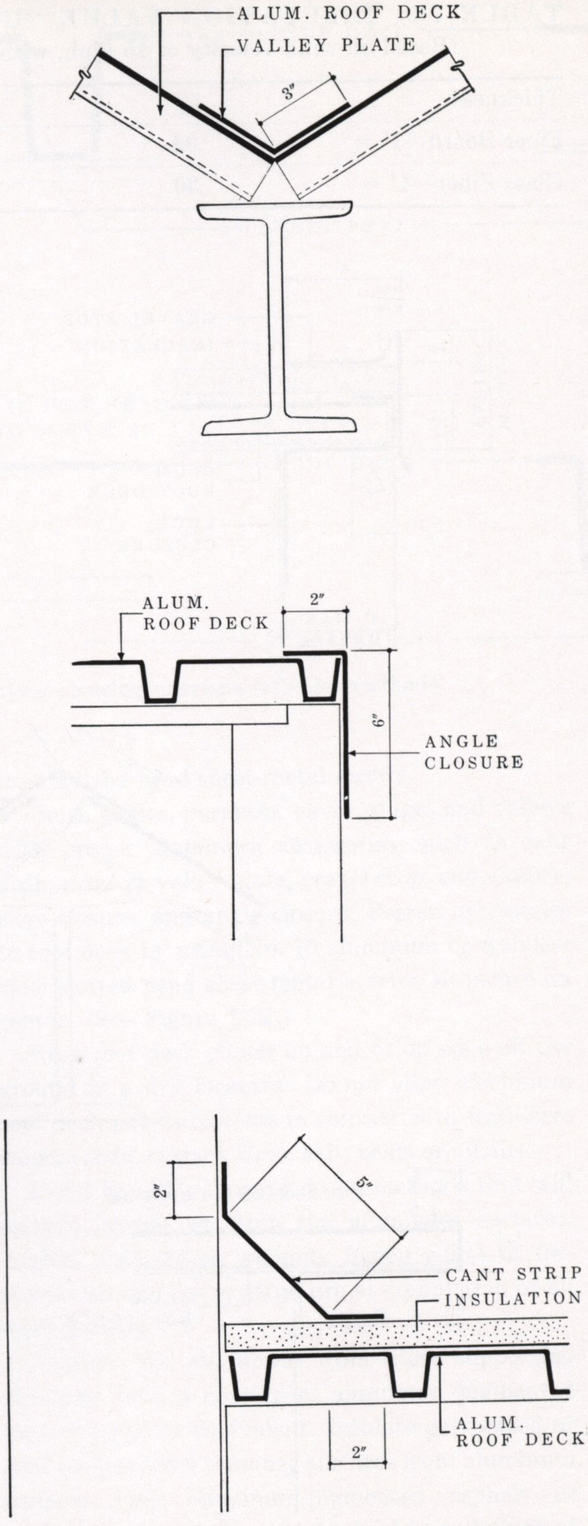


Figure 7-22: Typical flashing accessories used in application of aluminum roof deck. Concluded from Page 199.

and shall not be permitted to come in contact with lime, acids or alkalis.

Loading and Support Spacing, Specifications: For recommended loading and support spacing, see Table 7-8.

7.4 PAN TYPE ROOFING

This type roofing has been in use for many years. The earliest known installation is on the semi-cupolas of the Gioacchino Church in Rome. They are covered with aluminum sheets riveted with aluminum rivets, and are about 65 feet above ground level and 12–15 miles from the sea. An examination in 1949 showed the exposed surface to be covered with a granular powder that formed an adherent coating. The unexposed aluminum had retained its original brightness with the exception of a few discolored strips. Generally, the roofing was reported to be in good condition and with only superficial atmospheric corrosion; the maximum depth of pitting was only 3 mils.

The usual gauges in use are B&S 20 (.032-inch) with a plain mill finish. These can be prefabricated so that any type of roof can be covered with a minimum of field work.

Some typical details of installing pan-type roofing are shown in Figures 7-23 to 7-25. Minimum recommended pitch for standing-seam roofing is 2 inches in 12 inches. Flat-seam roofs are used for pitches less than 4 inches in 12 inches, minimum pitch ½-inch in 12 inches. Ribbed-seam roofs (see Figure 7-26) require a minimum pitch of 4 inches in 12 inches. Roofing is applied over wood battens as in Figure 7-27.

Batten Bar Installation: This type is suitable for roofs with a minimum pitch of 1½ inches in 12 inches. It can be applied to pitched roofs, high roofs, domes, spires and the like. The sheets are prefabricated to job specifications. The sheets are applied over one layer of 30 pound saturated felt laid on the deck, and are joined by mechanical interlocking joints. Figure 7-27 shows a typical application. The lower batten bar is held to the roof deck by the batten bar clip. The roofing sheets are hooked over

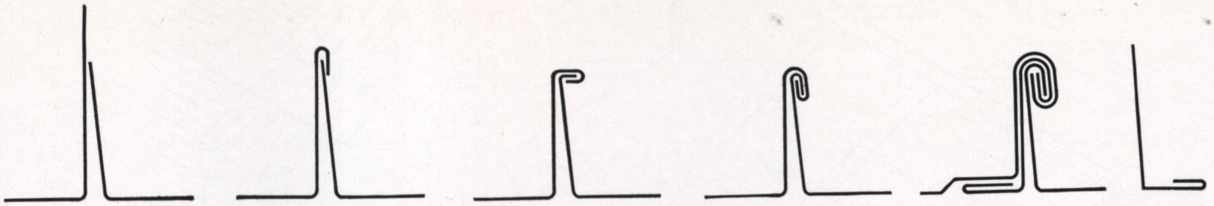
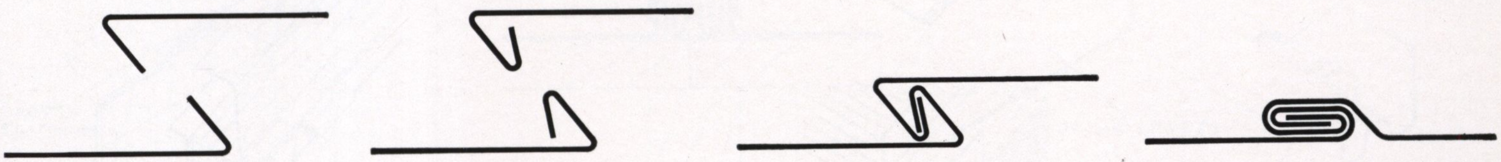
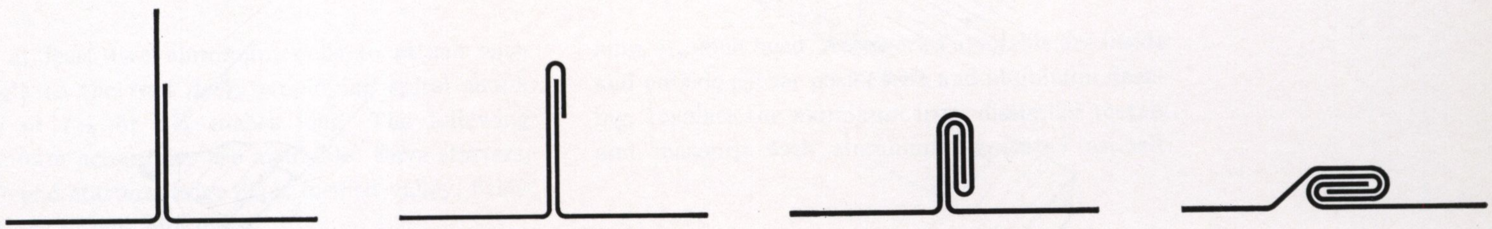


Figure 7-23: Standing-seam detail as formed on the job, for use with pan type roofing.

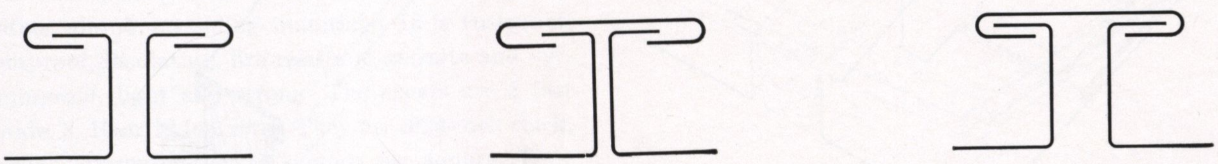


(A) FORMED IN THE SHOP



(B) FORMED ON THE JOB

Figure 7-24: Double lock-seam detail, for use with pan type roofing.



AT INSTALLATION   EXPANDED   CONTRACTED

Figure 7-25: Expansion joint detail, for use with pan type roofing.

the edges of this batten bar. The joint is then covered by a batten cap which is applied by using ¼ x ⅞-inch aluminum machine screws threaded into the batten clip.

7.5 ROOF SHINGLES

Shingles in Figure 7-28 have a 14½-inch x 8-inch exposed surface, and are made by Reynolds Metals. They have a shadow-cap design and are used for

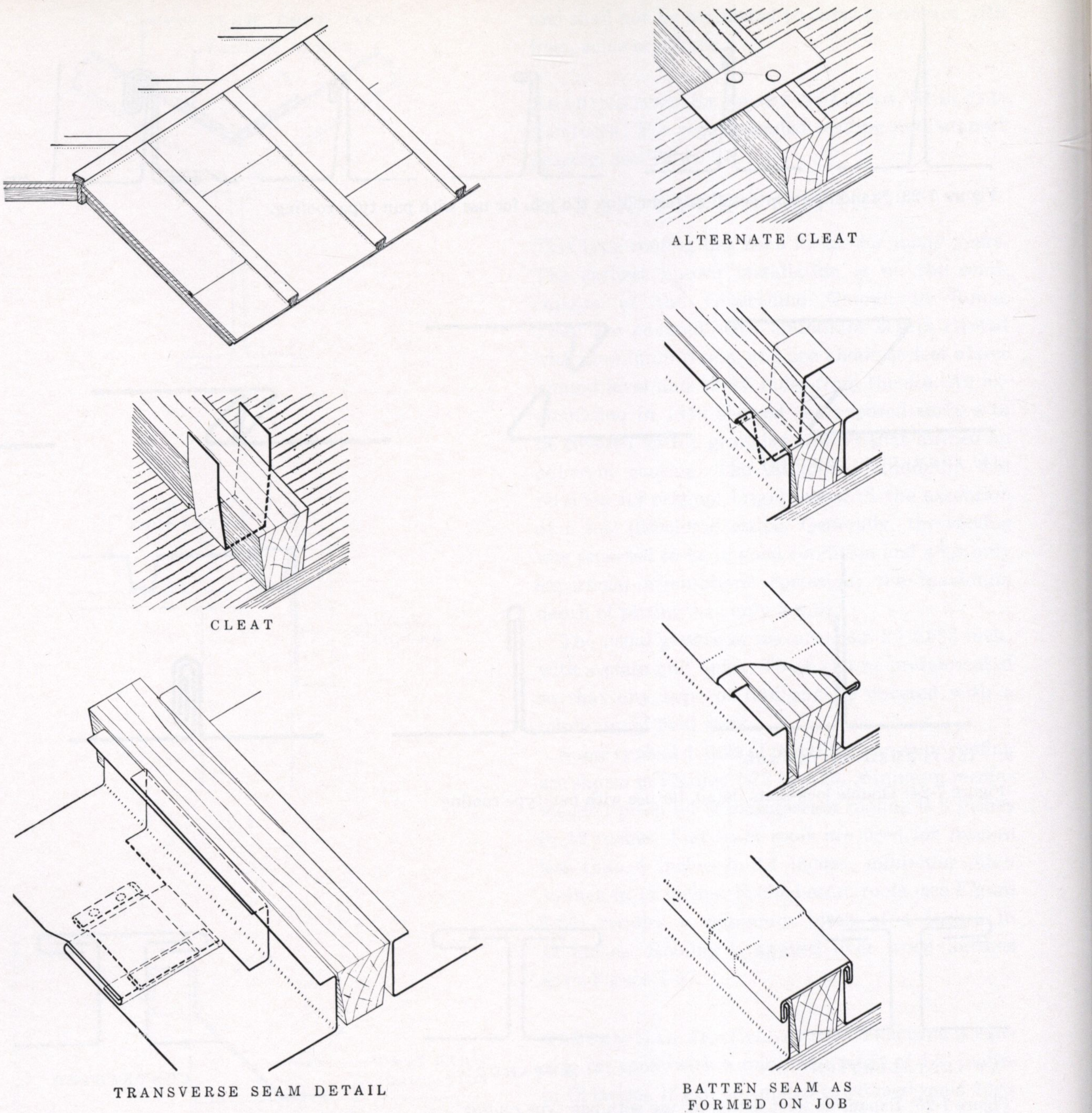


Figure 7-26: Ribbed-seam roofing details for use with pan type aluminum roofing.

new construction or remodeling of homes, schools, churches, institutions or commercial buildings. They are impervious to rust, rot, and insulate by reflecting heat. They are available in a stipple embossed or wood grain finish.

Application: The shingles are applied on solid wood decking over 30-pound asphalt saturated felt. The sides of shingles interlock so as to form an air space that resists capillary action of water between shingles. Minimum roof pitch—4 inches per foot.

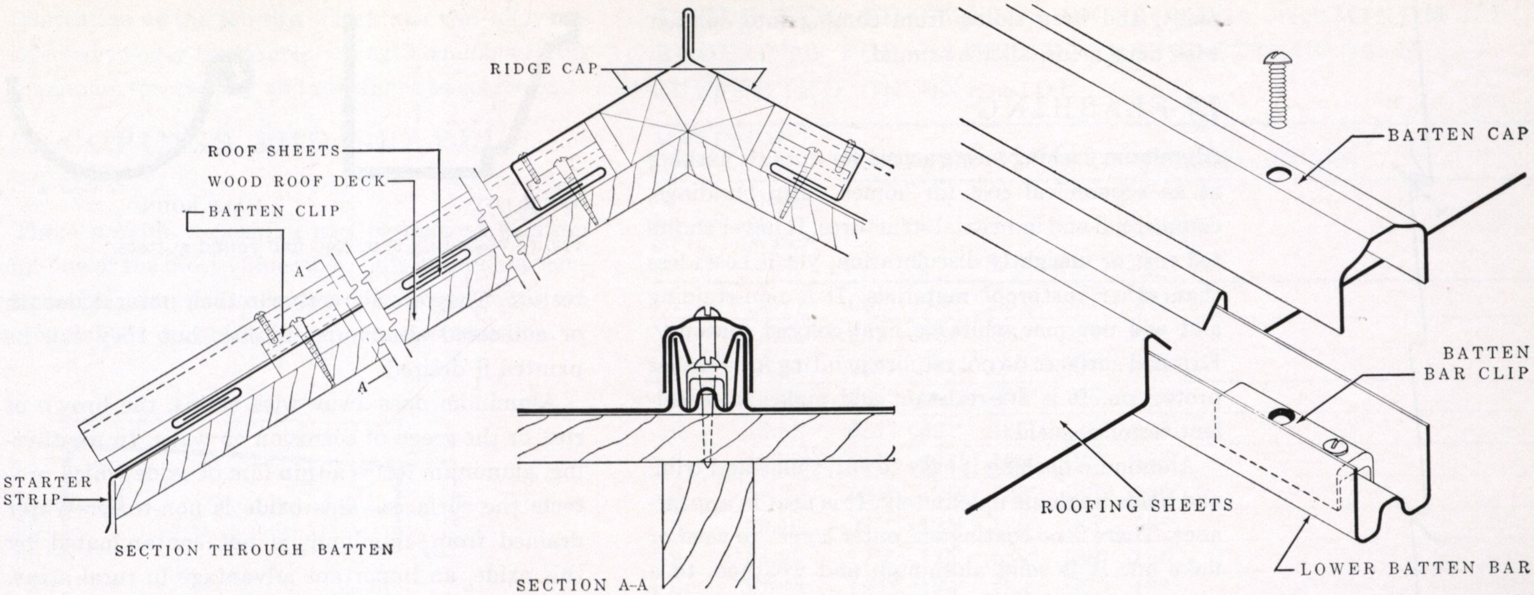


Figure 7-27: Batten bar installation details for use with pan type aluminum roofing.

Use at least two aluminum nails to attach each shingle to the roof deck, employing spiral shank nails of 1¼ or 1¾ inches long. The following aluminum accessories are available: Eave starters, gable end starters, ridge caps, formed valley, flashing sheet or coil, and nails.

7.6 WEATHERBOARD SIDING

The siding in Figure 7-29 has multiple clapboard-like surfaces. It is made by Reynolds Metals. It is used on residences, farm buildings and also commercial structures. It has the same advantages as other aluminum siding materials: It is rustproof, rotproof, insulating, fire resistant, termite and verminproof, light and strong. The sheets are 2 feet wide, 8, 10 or 12 feet long. They are .024-inch thick, weigh approximately 41 pounds per square. They are available in three finishes: Smooth mill finish, stipple embossed and wood grain embossed.

APPLICATION: Cover sheathing with water-resistant building paper. Fasten siding with aluminum nails at every other shadow line on 16-inch centers, nailing at an angle into the corner of the shadow line. (See Figure 7-29.) Lap panels at ends a minimum of 2 inches. Use spiral shank nails 1½ inches long, 5⁄16-inch head. Accessories available are inside and outside corner posts, trim and aluminum flashing. Insulate the aluminum from dissimilar metals and masonry with aluminum-pigmented asphalt

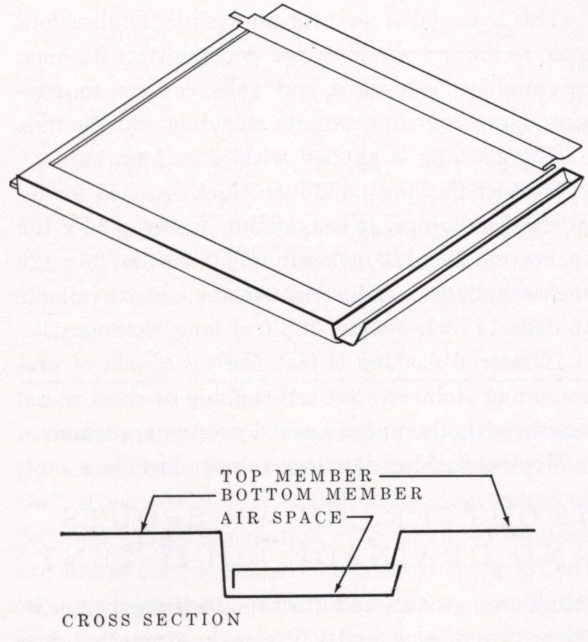


Figure 7-28: Aluminum roof shingle.

paint, and keep siding from coming into contact with lime, acids, alkalis or mud.

7.7 FLASHING

Aluminum flashing meets a need for durable flashing at an economical cost for homes, farm buildings, commercial and industrial structures. It never shows red rust or unsightly discoloration, yet it costs less than other rustproof materials. It is non-staining and will not mar white or light-colored masonry. Exposed surfaces do not require painting for weather protection. It is fire-resistant and makes an excellent termite shield.

Aluminum flashing is easy to cut, shape and trim, and holds its shape indefinitely. It is neat in appearance. There is no coating or "outer layer" to wear or flake off. It is solid aluminum and weathers to a pleasing neutral finish.

The flashing material is available in flat sheets or in rolls. The sheet comes in 18 x 48-inch sheets, No. 26 U.S. gauge (.019-inch thick). Roll flashing is available in No. 26 U.S. gauge (.019-inch thick) in rolls 14, 20 or 28 inches wide and 50 feet long, or No. 24 U.S. gauge (.024-inch thick) in rolls 6 inches wide and 100 feet long, or 20 inches wide and 50 feet long.

This material is used for all flashing applications such as around windows and doors, gutter flashing, at chimneys, side walls, end walls, corners, foundation damp-coursing, termite shielding and the like.

This flashing is applied with aluminum nails.

Heavier flashing (.032-inch thick) is used for industrial buildings. It is available in sheets 36 x 120 inches and 28 x 120 inches in mill finish and 36 x 120 inches embossed. Industrial flashing is also available in coils 14 inches wide, 186 feet long, embossed.

Industrial flashing is fastened by means of aluminum or stainless steel self-tapping or sheet metal screws with aluminum backed neoprene washers.

Typical flashing details are shown in Figure 7-14.

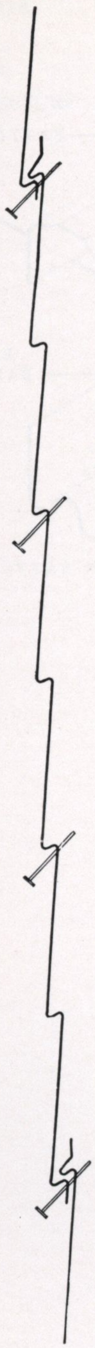


Figure 7-29: Application of weatherboard siding.

7.8 GUTTERS, DOWN SPOUTS AND DRAINAGE EQUIPMENT

Aluminum gutters and downspouts are permanent. They cannot rust and will remain attractive year after year. No painting is required for weather protection. They are attractive in their natural smooth or embossed aluminum finishes, but they can be painted if desired.

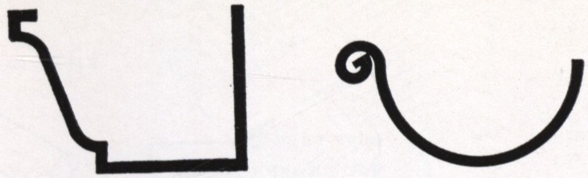


Figure 7-30: Box type and half-round gutters.

Aluminum does away with stains, the brown of rust or the green of corrosion on walls. In weathering, aluminum forms a thin film of oxide which protects the surfaces. This oxide is non-toxic. Water drained from aluminum is not contaminated by this oxide, an important advantage in rural areas.

These gutters are light and strong—one-third to one-half lighter than traditional materials for gutters and downspouts. They are easier to handle, lighter on the eaves, hangers and the nails that hold them.

GUTTERS are available in two types, half round or box type; in two finishes, plain or embossed; and are .027-inch thick. The 4-inch OGEE is .02-inch thick.

DOWNSPOUTS are plain round, corrugated round or rectangular, of plain or embossed finished aluminum of .020-inch thickness. Conductor pipe and elbows have one end crimped to fit into the adjoining piece.

INSTALLATION: Gutters and downspouts are installed with slip joints, requiring no solder. Typical details and accessories are shown in Figure 4-69 (Chapter 4).

Hangers for gutters are also of aluminum and are spaced 30 and 36 inches on centers. Conductor pipe is held in place by the use of two aluminum bands per 10-foot length of pipe.

INDUSTRIAL ROOF-DRAINAGE MATERIAL is mill finish aluminum, .032 to .188-inch thick. It is available in unformed flat sheets, 36 inches or 48 inches wide and 96, 120 or 144 inches long, ready for

fabrication at the job site. Thickness and alloy are selected to offer the desired strength combined with maximum formability and resistance to corrosion.

7.9 COPINGS AND GRAVEL STOPS

These provide a positive and permanent solution for one of the most vulnerable spots in building construction. Aluminum copings and gravel stops are economical, durable, do not require painting or

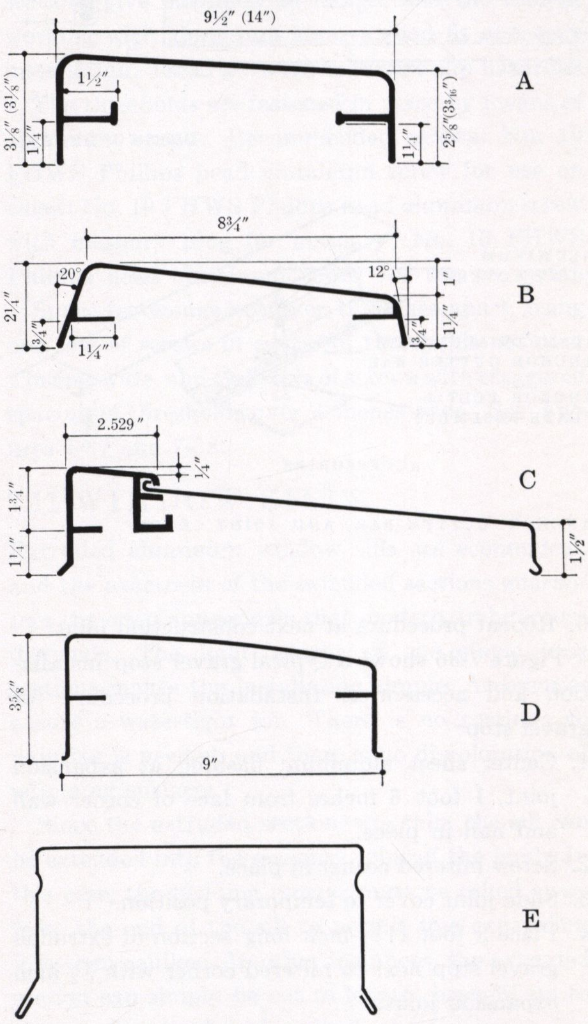


Figure 7-31: Typical coping sections. "A" is for 8 and 12-inch walls, "B" and "D" are for 8-inch walls. "C" is for any wall thickness; this type combines an extruded shape with formed sheet aluminum. "E" is a sheet aluminum coping, used where economy is the first consideration. Variations of this basic design can easily be executed in any sheet-metal shop.

TABLE 7-10: THICKNESS OF 3003-H14 ALUMINUM REQUIRED FOR EAVE GUTTER CONTINUOUSLY SUPPORTED ON ONE SIDE

MAXIMUM LIVE LOAD		MAXIMUM WIDTH OF GUTTER—INCHES				
Lbs per Sq In.	Depth of Water in In.	6	7	8	9	10
.1	2.77	.032″	.040″	.051″	.051″	.064″
.2	5.54	.051″	.064″	.064″	.081″	.081″
.3	8.31	.064″	.064″	.081″	.091″	.091″
.4	11.08	.064″	.081″	.091″	.125″	.125″
.5	13.85	.081″	.091″	.125″	.125″	.125″
.6	16.62	.081″	.091″	.125″	.125″	.188″
.7	19.39	.091″	.125″	.125″	.188″	.188″
.8	22.16	.091″	.125″	.125″	.188″	.188″
.9	24.93	.125″	.125″	.188″	.188″	.188″
1.0	27.70	.125″	.125″	.188″	.188″	.188″

TABLE 7-11: THICKNESS OF 3003-H14 ALUMINUM REQUIRED FOR VALLEY GUTTER CONTINUOUSLY SUPPORTED ON BOTH SIDES

MAXIMUM LIVE LOAD		MAXIMUM WIDTH OF GUTTER—INCHES									
Lbs per Sq In.	Depth of Water in In.	10	12	14	16	18	20	22	24	26	28
.1	2.77	.032″	.032″	.040″	.051″	.051″	.064″	.064″	.064″	.081″	.081″
.2	5.54	.040″	.051″	.064″	.064″	.081″	.081″	.091″	.091″	.125″	.125″
.3	8.31	.051″	.064″	.064″	.081″	.091″	.091″	.125″	.125″	.125″	.188″
.4	11.08	.064″	.064″	.081″	.091″	.125″	.125″	.125″	.188″	.188″	.188″
.5	13.85	.064″	.081″	.091″	.125″	.125″	.125″	.188″	.188″	.188″	.188″
.6	16.62	.081″	.081″	.091″	.125″	.125″	.188″	.188″	.188″	.188″	
.7	19.39	.081″	.091″	.125″	.125″	.188″	.188″	.188″	.188″		
.8	22.16	.081″	.091″	.125″	.125″	.188″	.188″	.188″			
.9	24.93	.091″	.125″	.125″	.188″	.188″	.188″	.188″			
1.0	27.70	.091″	.125″	.125″	.188″	.188″	.188″				

maintenance, and are rustproof. The extruded sections and cover plates provide a water-sealed unit that is very simple to install. The long length of sections speeds installation. The extruded sections are sharp, precise and straight, which is a great advantage from the architectural point of view. There is a variety of standard sections to satisfy most needs. Special requirements can be met at relatively

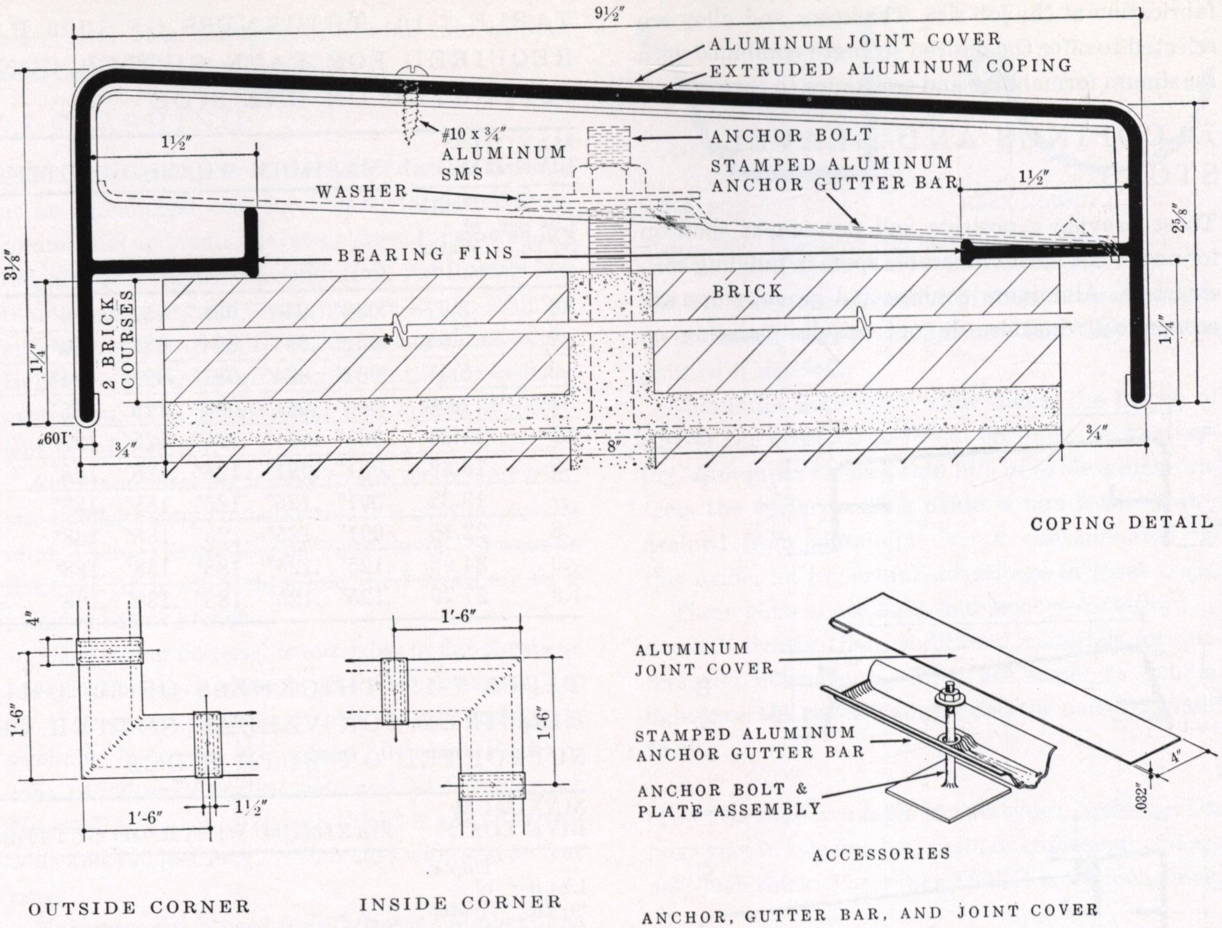


Figure 7-32: Coping installation and accessories.

low cost. Figure 7-31 illustrates typical coping sections. Figure 7-32 shows a typical coping installation. Anchor-plate and bolt assemblies are placed during construction. The first assembly is placed 1 foot 5¼ inches from face of corner; successive anchor-plate assemblies are located at 10-foot intervals. Installation procedure for coping:

1. Set mitered corner in place.
2. Loosely bolt anchor gutter bar in place.
3. Place bearing fins of coping under anchor gutter bar allow 1½ inches for expansion and contraction joint.
4. Fasten anchor gutter bar.
5. Place formed lip of joint over outside drip edge of coping section and bend in place. Secure joint cover to one coping section only by crimping or with aluminum sheet-metal screw.
6. Repeat procedure at next construction joint.

Figure 7-36 shows a typical gravel stop installation and accessories. Installation procedure for gravel stop:

1. Center sheet aluminum flashing at expansion joint, 1 foot 6 inches from face of corner wall and nail in place.
2. Screw mitered corner in place.
3. Slide joint cover to temporary position.
4. Place 9 foot 11½-inch long section of extruded gravel stop next to mitered corner with ½-inch expansion joint.
5. Screw gravel stop section at mid-point in two places.
6. Place bed of plastic roofing cement at expansion joint.
7. Slide the joint cover over the expansion joint

and then screw securely in place.

8. Repeat procedure at the next expansion joint.

7.10 THRESHOLDS

Extruded aluminum thresholds are economical in first cost and maintenance—lowest in cost of the non-rusting metals. There is a variety of types both for exterior and interior doors, including floor pivot doors.

Types designed for exterior entrances have provision for weatherstripping. The lengths of stocked sections give flexibility in design, and the ease of working with aluminum assures good fit and easy installation. Tread patterns minimize slip hazards.

The thresholds are fastened in place by means of aluminum screws. Recommended screws: No. 10 FHWS Phillips head aluminum screw for use on wood; No. 10 FHWS Phillips head aluminum screw with masonry plug for masonry; No. 10 FHWS Phillips head aluminum screw for use on metal.

Space fastenings not over 10 inches apart, using one row of screws in center of thresholds not over 4 inches wide, and two rows of screws with staggered spacing in thresholds over 4 inches wide. See Figures 7-37 and 7-38.

7.11 WINDOW SILLS

Extruded aluminum window sills are economical, and the exactness of the extruded sections guarantees the crisp appearance that modern architecture demands. The light weight of the single long sections makes the installation simple. Accessories ensure a watertight job. There is no rusting; no painting is needed; and there is no discoloration of adjoining surfaces.

Since the extruded sections are thin, the sill can be extended into the masonry joint of the jamb. In this case, the bedding mortar must be raked away from the end of the sill to permit free expansion; it is then caulked. In other instances, the extruded section can simply be cut to length, brought up to the masonry jamb and caulked.

In the case of long sills or continuous sills with butted sections, expansion space of about 0.02-inch per foot of length must be provided. Long sills must be secured with anchor clips not more than 3 feet

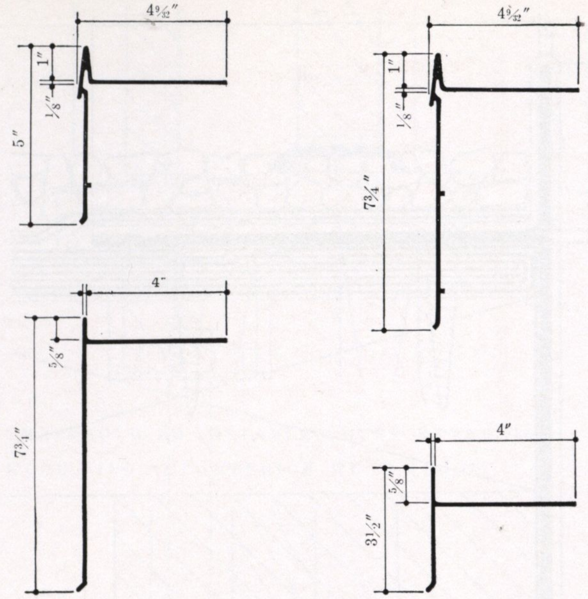


Figure 7-33: Standard gravel stops.

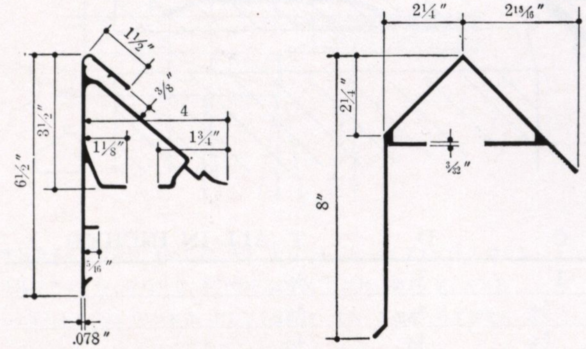


Figure 7-34: Combination gravel stops. At left: One-piece extrusion that combines gravel stop, cant strip terminal cap for roof membrane and fascia band. At right: Combination gravel stop, coping, terminal cap for roof membrane and fascia band.

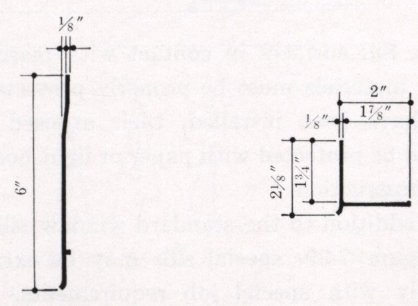
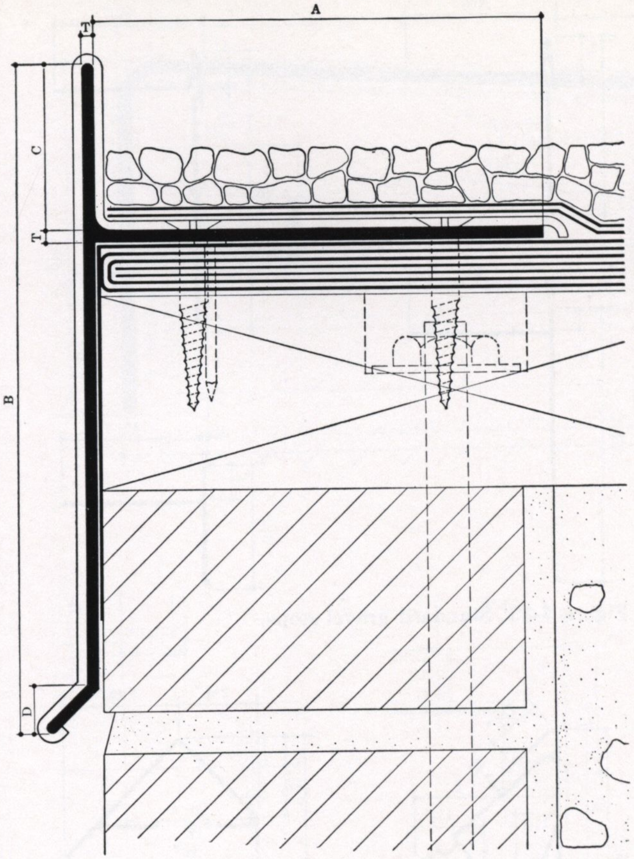
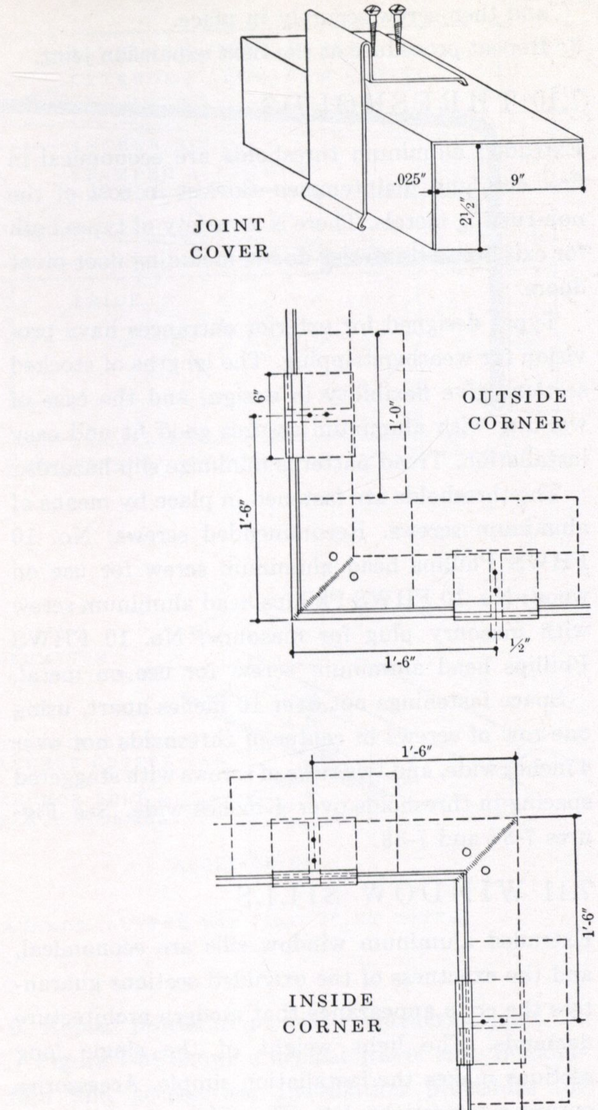


Figure 7-35: Fascia and soffit drip plates. Gravel stops are often used in combination with additional extruded aluminum fascia plates and soffit drip plates.





A	B	C	D	T (ALL IN INCHES)
4	5	1	7⁄16	3⁄32
4	3½	5⁄8	9⁄32	3⁄32
4	7¾	5⁄8	¼	1⁄8
4	6½	¾	3⁄8	3⁄32
4	6	1½	17⁄32	3⁄32

Figure 7-36: Gravel stop installation and accessories.

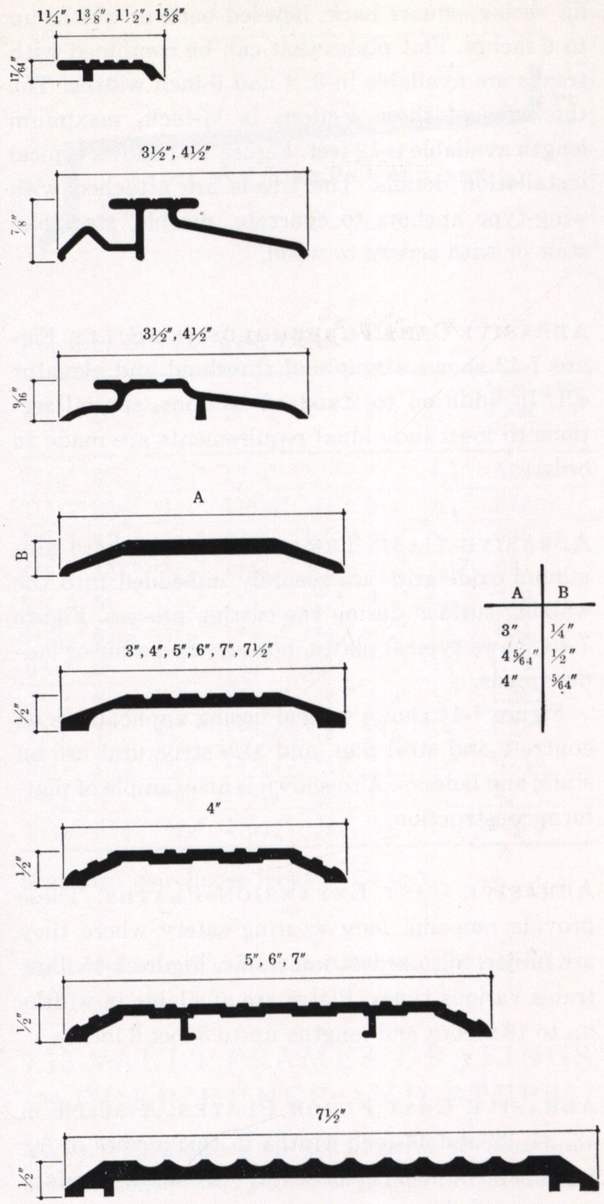
apart. Sill surfaces in contact with masonry and other materials must be properly protected. After sills have been installed, their exposed surfaces should be protected with paper or light boards during construction.

In addition to the standard window sills shown in Figure 7-39, special sills may be extruded to comply with special job requirements. The die charge is negligible when prorated over the quantity of sills required for a large size building.

7.12 SAFETY TREADS

In public buildings, industrial plants and other places where treads will receive heavy traffic, rough usage or exposure, it is necessary to use plates, treads and nosings with special surfacing. Accompanying illustrations show typical examples.

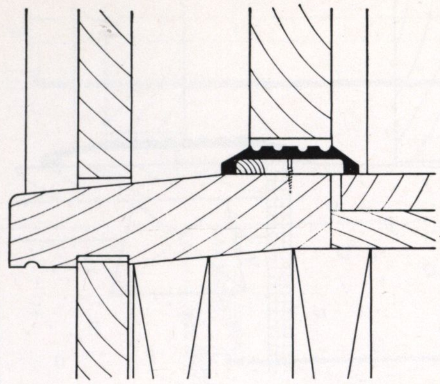
Safe-Groove Treads: These are used where fine appearance is a factor, such as in office build-



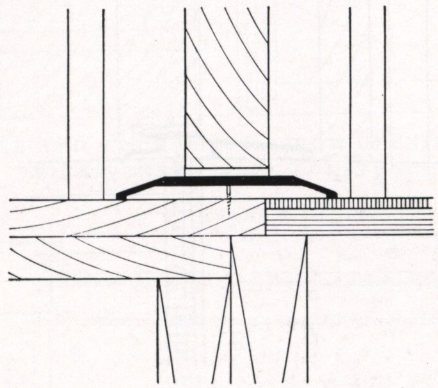
THRESHOLDS

Figure 7-37: Standard extruded aluminum thresholds.

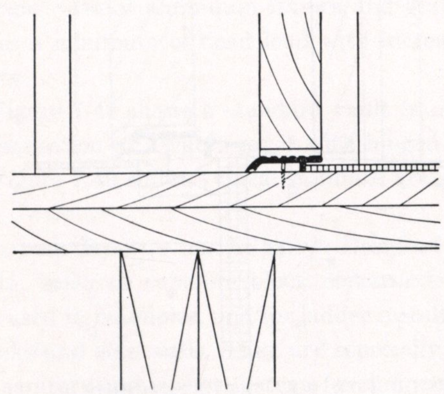
ings, churches, schools and the like. Absolute uniformity of size and thickness makes them particularly adaptable in combination with other floor materials to ensure a perfect fit. The heat-treated extruded aluminum base has fillers of anti-slip lead or of abrasive grits. Figure 7-40 shows examples of various types. Treads are available with long nosing,



THRESHOLD AS INSTALLED OVER EXTERIOR WOOD SILL AND INTERIOR WOOD FLOOR.

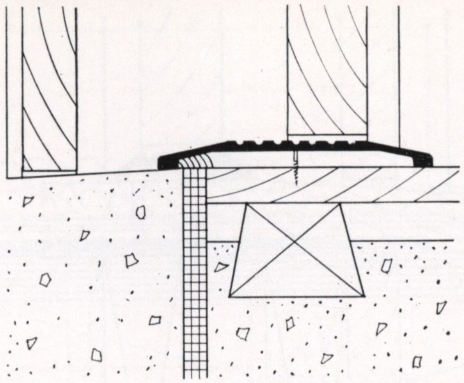


THRESHOLD USED AT DOUBLE-ACTING DOOR. SHOWING WOOD FLOOR IN ONE ROOM AND LINOLEUM OVER PLYWOOD IN THE OTHER.

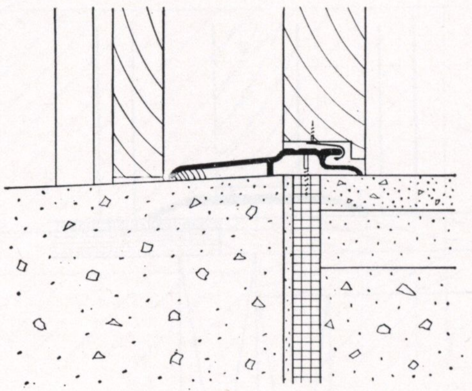


THRESHOLD OVER WOOD FLOOR ACTING AS LINOLEUM STOP.

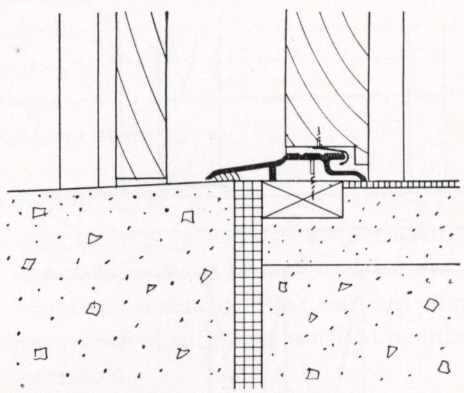
Figure 7-38: Typical threshold installations. These are concluded on Page 210.



THRESHOLD USED OVER EXTERIOR CONCRETE SILL. THE INTERIOR FLOOR IS WOOD LAID OVER CONCRETE SLAB.



ALUMINUM THRESHOLD FOR WEATHERSTRIPPED DOOR. SHOWN WITH EXTERIOR STONE SILL AND INTERIOR FLOOR OF TILE LAID OVER CONCRETE SLAB.



THRESHOLD FOR WEATHERSTRIPPED DOOR SHOWN OVER EXTERIOR MASONRY SILL. INTERIOR FLOOR IS LINOLEUM LAID OVER CONCRETE SLAB.

Figure 7-38: Typical threshold installations, concluded.

lip nosing, square back, beveled back in widths up to 6 inches. Flat plates that can be combined with treads are available in 3, 4 and 6-inch widths. The thickness of these sections is ¼-inch, maximum length available is 12 feet. Figure 7-41 shows typical installation details. The treads are attached with wing-type anchors to concrete, marble, steel pan stair or with screws to wood.

Abrasive Cast Thresholds and Sills: Figure 7-42 shows example of threshold and elevator sill. In addition to standard sections, special sections to meet individual requirements are made to order.

Abrasive Cast Treads: Diamond hard aluminum oxide grits are securely imbedded into the walking surface during the casting process. Figure 7-43 shows typical plates, nosings, and stair or ladder treads.

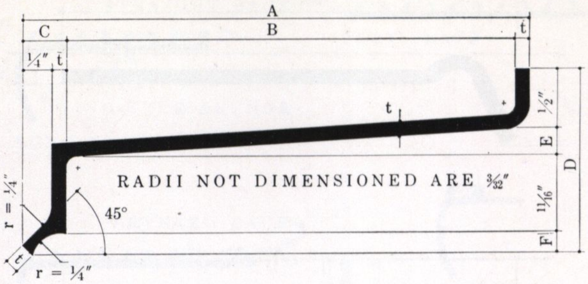
Figure 7-44 shows typical nosing applications on concrete and steel pan, and also structural use on stairs and ladders. Also shown is an example of platform construction.

Abrasive Cast Expansion Plates: These provide non-slip, long wearing safety where they are subjected to pedestrian traffic. Figure 7-45 illustrates various types. Plates are available in widths up to 16 inches and lengths up to 8 feet 6 inches.

Abrasive Cast Floor Plates: Available in 12, 24, 32 and 44-inch widths in thicknesses of ⅜, 7/16, ½ and ⅝-inch, respectively. Crosshatch surface recommended.

Trench and Drain Covers: Available in solid plates (24 and 44 inches wide), with diamond openings (24 and 44 inches wide) and with open slots (36 inches wide). See Figure 7-46 for setting in cast frame.

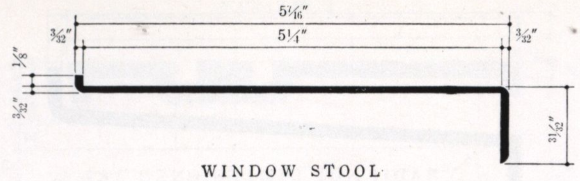
Abrasive Cast Curb Bars: Available in lengths of 5 feet maximum. Section shown in Figure 7-47.



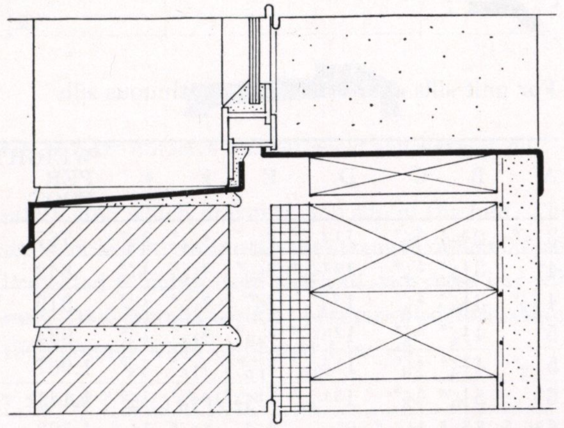
For unit sills not over 6 feet

A	B	C	D	E	F	t	WEIGHT PER FOOT
3 7/16"	3"	11/32"	1 9/16"	3/16"	3/16"	3/32"	.524
3 15/16"	3 1/2"	11/32"	1 19/32"	7/32"	3/16"	3/32"	.574
4 7/16"	4"	11/32"	1 5/8"	1/4"	3/16"	3/32"	.636
4 15/16"	4 1/2"	11/32"	1 21/32"	9/32"	3/16"	3/32"	.691
5 7/16"	5"	11/32"	1 11/16"	5/16"	3/16"	3/32"	.746
5 15/16"	5 1/2"	11/32"	1 23/32"	11/32"	3/16"	3/32"	.804
6 1/2"	6"	3/8"	1 3/4"	3/8"	3/16"	1/8"	1.147
7"	6 1/2"	3/8"	1 25/32"	13/32"	3/16"	1/8"	1.222
7 1/2"	7"	3/8"	1 13/16"	7/16"	3/16"	1/8"	1.297
8 1/16"	7 1/2"	13/32"	1 29/32"	15/32"	1/4"	5/32"	1.716
8 9/16"	8"	13/32"	1 15/16"	1/2"	1/4"	5/32"	1.710
9 1/16"	8 1/2"	13/32"	1 31/32"	17/32"	1/4"	5/32"	1.903

Standard warehouse length—20 feet



WINDOW STOOL



SILL AND STOOL FOR NARROW OPENINGS IN BRICK VENEER WALL CONSTRUCTION

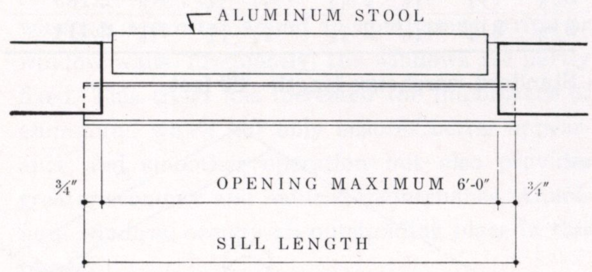


Figure 7-39: Standard window sills. See also Page 212.

7.13 VAULT FRAMES, GRATINGS, LADDER RUNGS AND STEPS

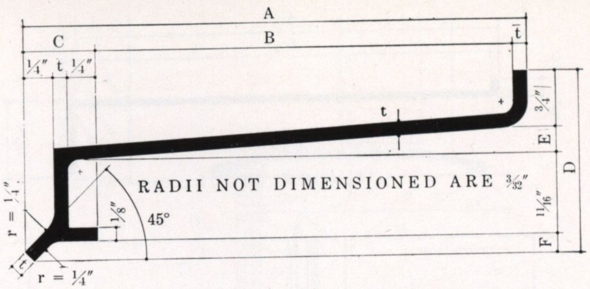
VAULT FRAMES AND GRATINGS of aluminum are frequently used in access panels to transformer vaults and junction boxes, manholes, for walkways and catwalks in boiler houses, refineries, ships and the like. In applications exposed to weather, their carefully designed tapers and close tolerances of mating sections minimize penetration of surface water. Their high resistance to corrosion assures ready access in emergencies. Inspection and maintenance are substantially reduced. The non-sparking characteristic of aluminum makes it especially suitable for use in vaults where explosive gases or dust accumulate. The favorable weight to cross-section ratio of aluminum frames and gratings assures a minimum of dead load with increased mobility.

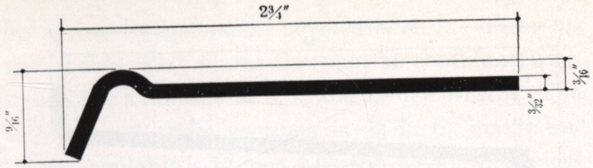
Figure 7-48 shows a standard vault frame and a cross-section of a vault cover with hinged grating.

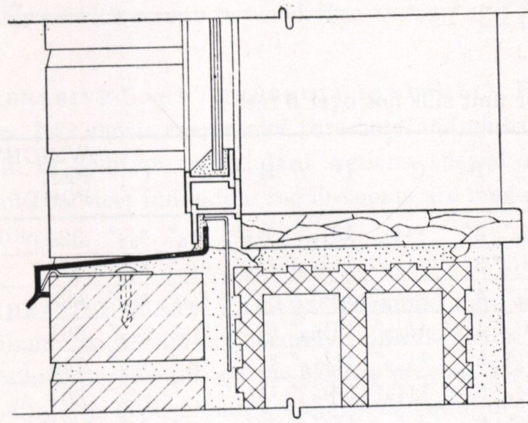
Figure 7-49 shows typical standard gratings.

LADDER RUNGS AND STEPS: Designed for concrete, brick or concrete block construction, these are used in manholes, and for ladder installation on stacks and side walls. They are especially suitable for sanitary and sewage systems for their non-sparking characteristic and ability to withstand the corrosive effects of these highly humid and gas-laden atmospheres.

Figure 7-50 illustrates the flat rungs and the



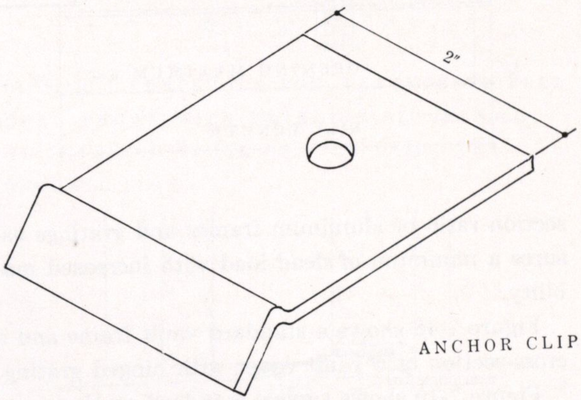


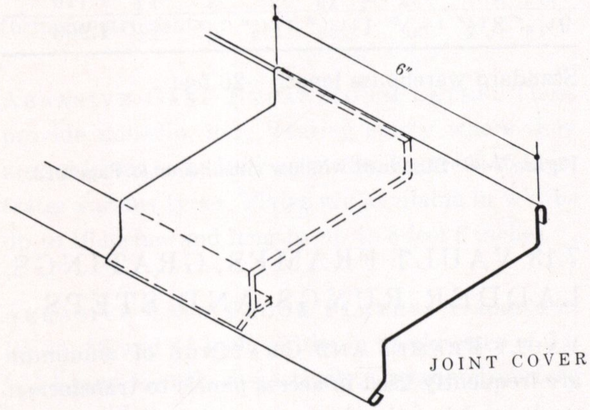


For unit sills over 6 feet and continuous sills

A	B	C	D	E	F	t	WEIGHT PER FOOT
3½″	2¾″	⅝″	1 13/16″	3/16″	3/16″	⅛″	.767
4″	3¼″	⅝″	1 27/32″	7/32″	3/16″	⅛″	.842
4½″	3¾″	⅝″	1⅞″	¼″	3/16″	⅛″	.919
5″	4¼″	⅝″	1 29/32″	9/32″	3/16″	⅛″	.994
5½″	4¾″	⅝″	1 15/16″	5/16″	3/16″	⅛″	1.067
6″	5¼″	⅝″	1 31/32″	11/32″	3/16″	⅛″	1.141
6 9/16″	5¾″	21/32″	2″	⅜″	3/16″	5/32″	1.529
7 9/16″	6¾″	21/32″	2 1/16″	7/16″	3/16″	5/32″	1.716
8⅛″	7¼″	11/16″	2 5/32″	15/32″	¼″	3/16″	2.189
9⅛″	8¼″	11/16″	2 7/32″	17/32″	¼″	3/16″	2.414

Standard warehouse length—20 feet





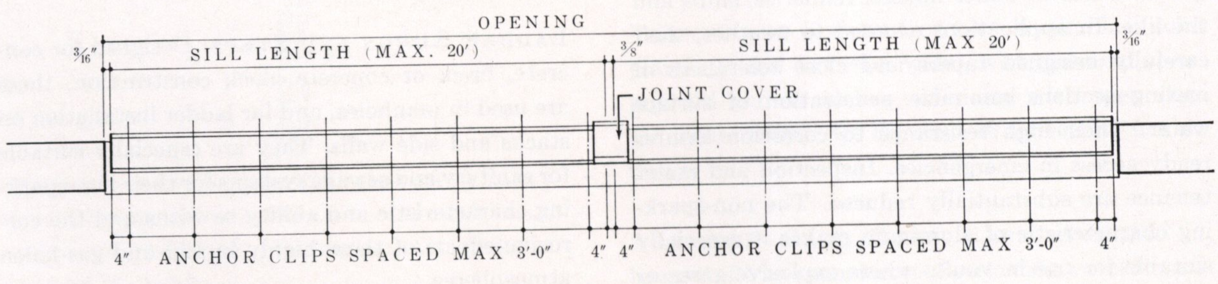


Figure 7-39: Standard window sills. Concluded from Page 211.

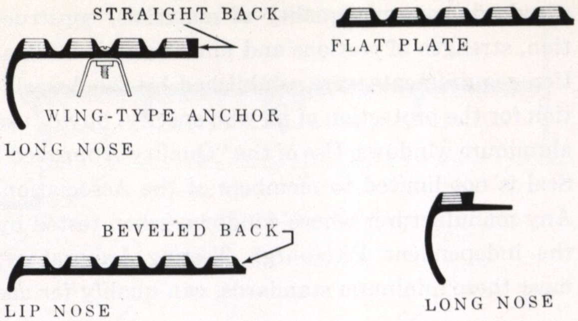


Figure 7-40: Typical safe-groove treads.

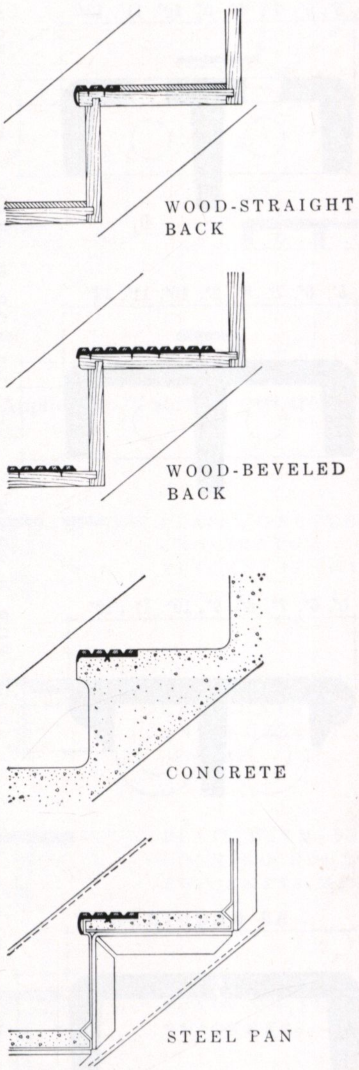


Figure 7-41: Safe-groove tread installation details.

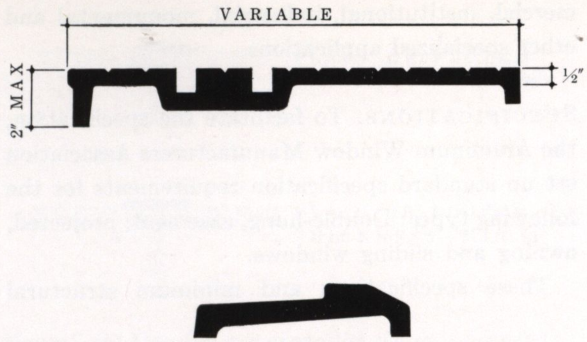


Figure 7-42: Abrasive cast threshold and elevator sill.

safety step which prevents side slip of the foot. The steps have a minimum tensile strength of 38,000 psi. Projected 6 inches from the wall, the cross bar will carry 1000 pounds without permanent deformation, 1500 pounds when projected 4 inches.

7.14 WINDOWS

Window areas have increased considerably in recent years. Instead of the traditional isolated window, windows are often found in continuous strips or window walls. Frequently, the windows are partly fixed. This trend has increased the importance of aluminum, which not only ensures better appearance and smoother operation but also provides greater economy and reduced maintenance. Aluminum windows occupy an outstanding place in this respect.

ADVANTAGES:

Strength of material permits slender members.
Light weight facilitates erection.
No painting needed.
Rustproof, non-staining.
Rotproof, termite-proof.
Corrosion resistant.
Fire resistant.
Not subject to swelling, splitting, warping.
Easy to clean.
Attractive appearance of narrow frames, increased glass areas.
Pleasing aluminum finish.

TYPES: A variety of types, sizes and grades offers a wide choice for all uses from residential to com-

mercial, institutional, industrial, monumental and other specialized applications.

SPECIFICATIONS: To facilitate the specification, the Aluminum Window Manufacturers Association set up standard specification requirements for the following types: Double-hung, casement, projected, awning and sliding windows.

These specifications and minimum structural standards covering quality of materials, construction, strength of sections and minimum air infiltration requirements were established by the Association for the protection of all who specify, buy or use aluminum windows. Use of the "Quality-Approved" Seal is not limited to members of the Association. Any manufacturer whose windows, when tested by the independent Pittsburgh Testing Laboratory, meet these minimum standards, can qualify for use

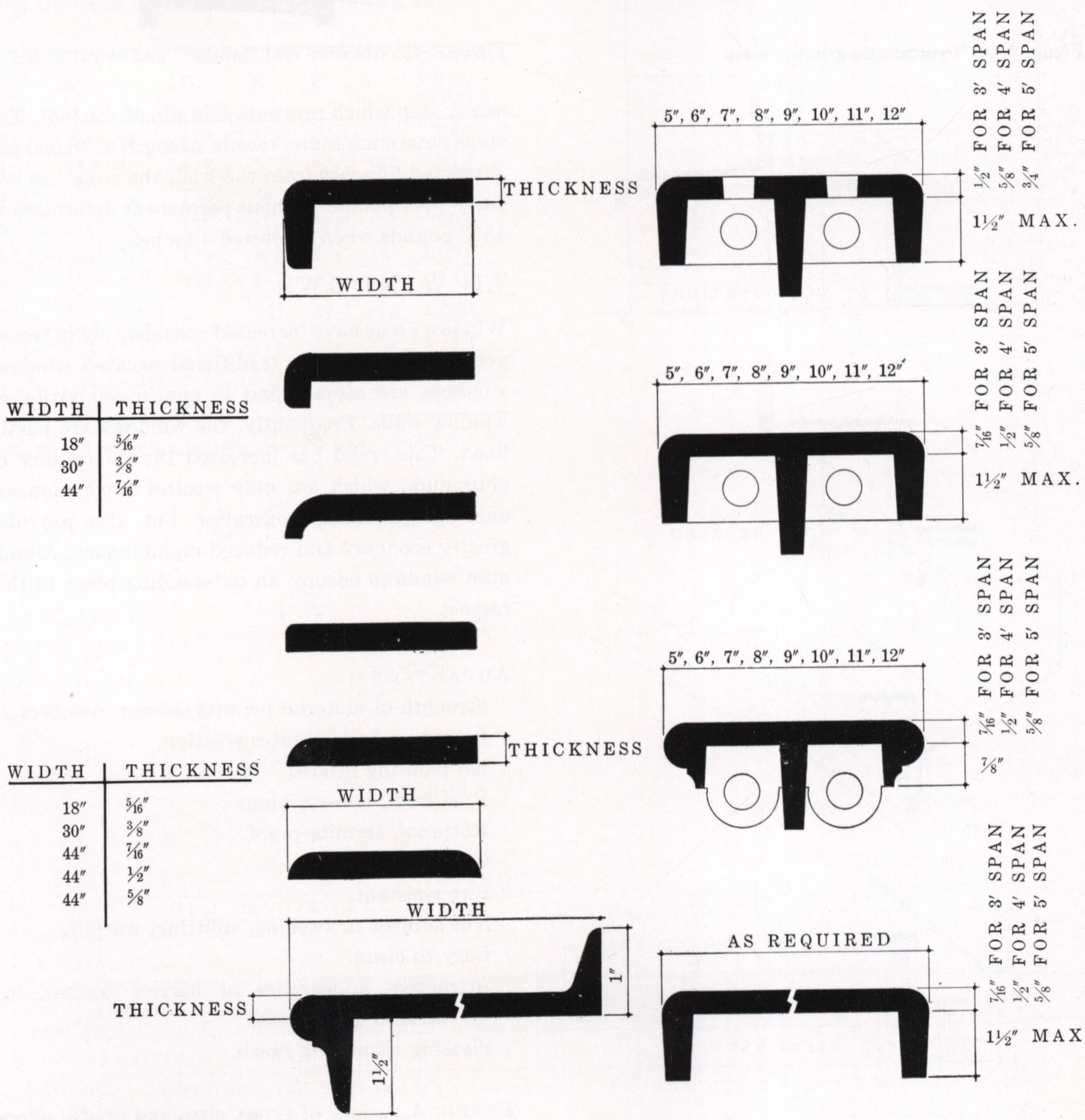


Figure 7-43: Typical abrasive cast treads.

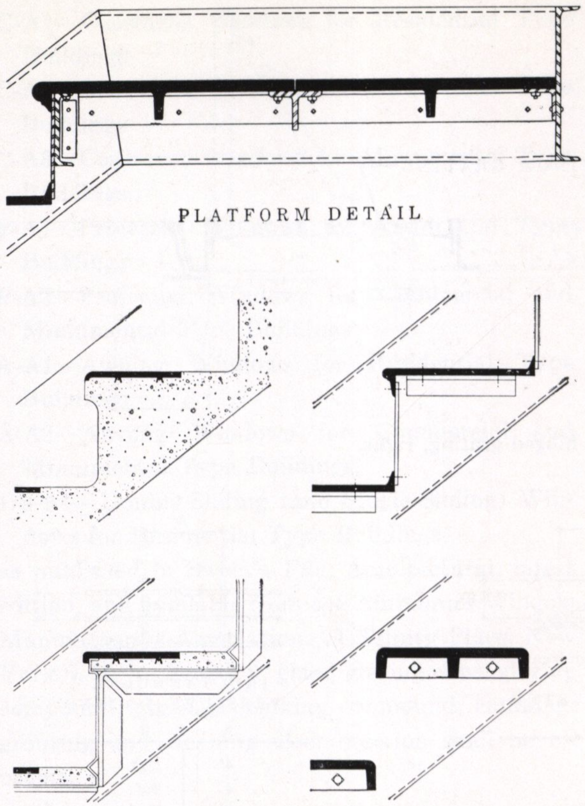


Figure 7-44: Application of abrasive cast treads on stairs and platforms.

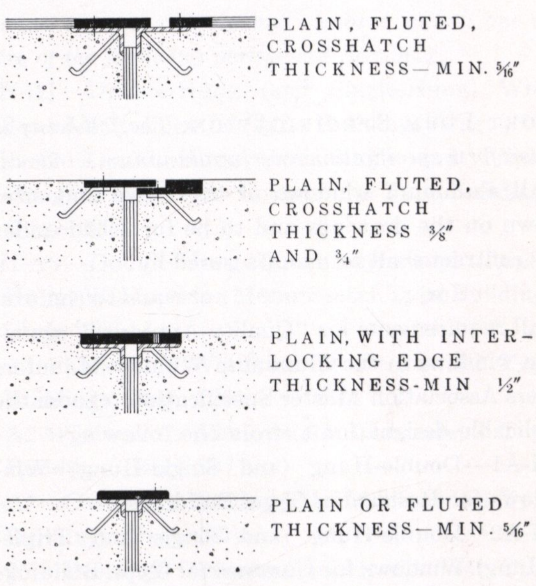


Figure 7-45: Abrasive cast expansion plates. See also the top of the next column on this page.

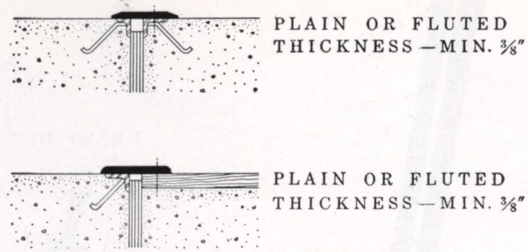


Figure 7-45: Abrasive cast expansion plates, concluded.

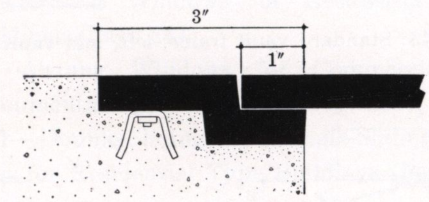


Figure 7-46: Trench cover detail.

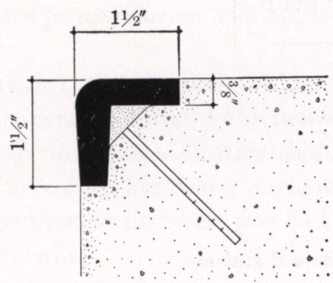


Figure 7-47: Curb bar detail.

of the "Quality-Approved" Seal.

The "Quality-Approved" Seal, featuring the copyrighted emblems of the Aluminum Window Manufacturers Association and of the Pittsburgh Testing Laboratory, is the joint guarantee of the Association and of the Laboratory, first (on the part of the Association) that these minimum specifications constitute the best judgment and experience of many years of responsible aluminum window manufacture and that, if followed in letter and spirit, will ensure a worthy product, and second (on the part of the Laboratory) that a sample of a particular window on which the "Quality-Approved" Seal is displayed did, in fact, meet or exceed these exacting requirements.

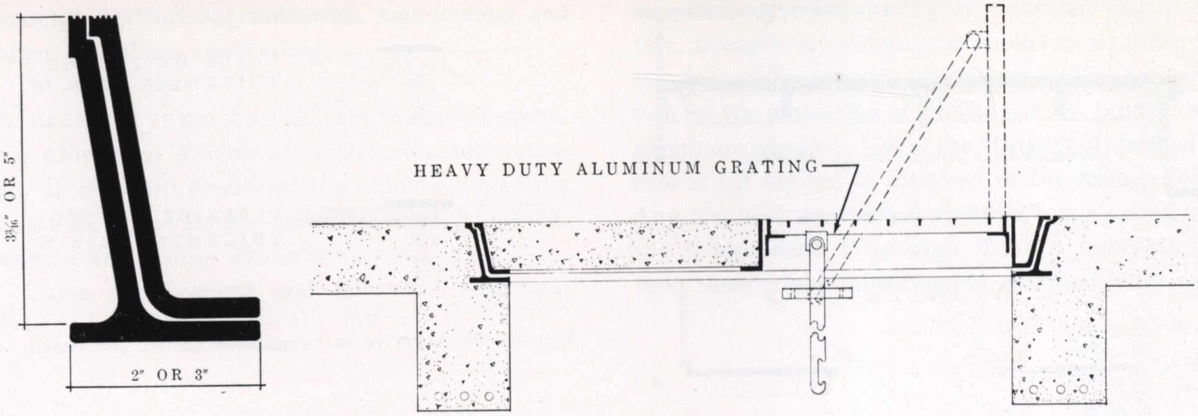
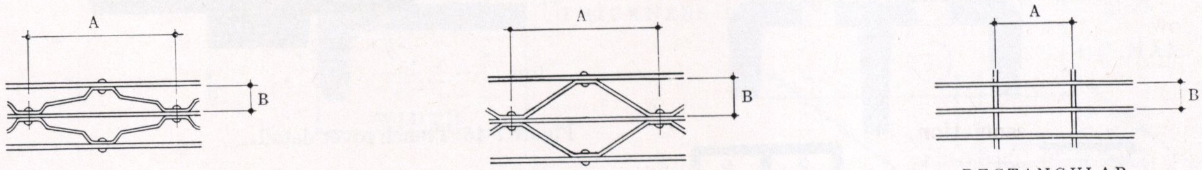


Figure 7-48: Standard vault frame, left, and vault cover with hinged grating, right.



DUPLEX-RIVETED

A	B
7"	1⅛"
7"	¾"
7"	1⅝"
3½"	1⅛"
3½"	¾"
5"	2 5/16"

SIMPLEX-RIVETED

A	B
7"	1⅛"
7"	¾"
7"	1⅝"
3½"	1⅛"
3½"	¾"
5"	2 5/16"

RECTANGULAR PRESSURE—LOCKED

A	B
4"	1 3/16"
4"	15/16"
2"	1 3/16"
2"	15/16"

Figure 7-49: Standard gratings.

In an endeavor to simplify the writing of specifications for "Quality-Approved" aluminum windows the Technical Committee of the Aluminum Window Manufacturers Association offers a short form specification as well as a complete master specification in two parts.

Use of the short form is recommended wherever possible. It may be used for any aluminum window merely by inserting the specific type or types ordered. The short form will save time, yet its use will assure full compliance on the part of the bidder with the complete detailed specification.

Where a complete detailed specification is required copy Section 1 in full. Then, follow with the specific portion of Section 2 that covers the type of windows to be used.

Short Form Specification: *The following is a short form specification covering aluminum windows:*

All aluminum windows of the types and sizes shown on the drawings and to be furnished under this contract shall be manufactured by . . . . or . . . . or equal to conform to all requirements for "Quality-Approved" aluminum windows in the Aluminum Window Manufacturers Association Master Specification (choose the applicable designation(s) from the following):

DH-A1—Double-Hung (and Single-Hung) Windows for Residential Type Buildings
DH-A2—Double-Hung (and Single and Triple-Hung) Windows for Commercial Type Buildings
DH-A3—Double-Hung (and Single and Triple-Hung) Windows for Monumental Type Buildings

C-A1—Casement Windows for Residential Type Buildings
C-A2—Casement Windows for Commercial Type Buildings
C-A3—Casement Windows for Monumental Type Buildings
P-A1—Projected Windows for Residential Type Buildings
P-A2—Projected Windows for Commercial and Monumental Type Buildings
A-A1—Awning Windows for Residential Type Buildings
A-A2—Awning Windows for Commercial and Monumental Type Buildings
DS-A1—Double-Sliding (and Single-Sliding) Windows for Residential Type Buildings

as published in Sweet's File, Architectural, latest edition, and available from the Aluminum Window Manufacturers Association, 74 Trinity Place, New York 6, N. Y. Erection, glass, glazing clips, glazing compound, glazing, caulking compound, caulking, grouting and cleaning after erection shall be by others.

MASTER SPECIFICATION: *To form a complete specification to cover aluminum windows of one or more types which you desire for your requirements, use Section 1 in its entirety and combine with it one or more of the following portions of Section 2:*

DH-A1—Double-Hung (and Single-Hung) Windows for Residential Type Buildings (Page 220)
DH-A2—Double-Hung (and Single and Triple-Hung) Windows for Commercial Type Buildings (Page 221)
DH-A3—Double-Hung (and Single and Triple-Hung) Windows for Monumental Type Buildings (Page 223)
C-A1—Casement Windows for Residential Type Buildings (Page 225)
C-A2—Casement Windows for Commercial Type Buildings (Page 227)
C-A3—Casement Windows for Monumental Type Buildings (Page 230)
P-A1—Projected Windows for Residential Type Buildings (Page 231)
P-A2—Projected Windows for Commercial and Monumental Type Buildings (Page 233)
A-A1—Awning Windows for Residential Type Buildings (Page 234)
A-A2—Awning Windows for Commercial and Monumental Type Buildings (Page 236)
DS-A1—Double-Sliding (and Single-Sliding) Windows for Residential Type Buildings (Page 239)

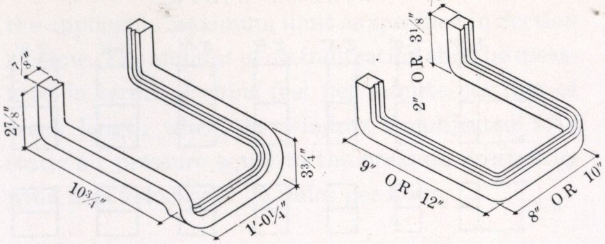


Figure 7-50: Safety step and flat rung.

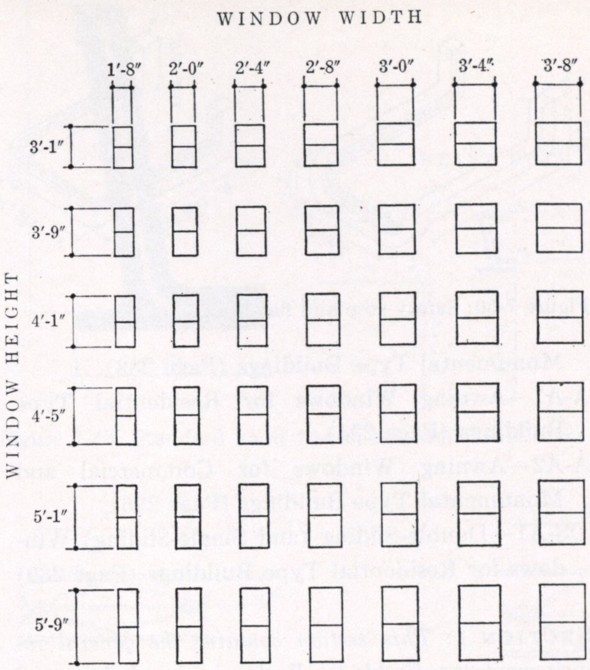
SECTION 1: *This section contains the general requirements applicable to all aluminum windows and is to be used in conjunction with Section 2.*

1.1 GENERAL AND SCOPE: All aluminum windows of the types and sizes shown in the plans and/or as called for in this specification shall be furnished with all necessary hardware, anchors and miscellaneous equipment as herein specified and shall be manufactured by .... or .... or equal. Erection, glass, glazing clips, glazing compound, glazing, caulking compound, caulking, grouting and cleaning after erection shall be by others.

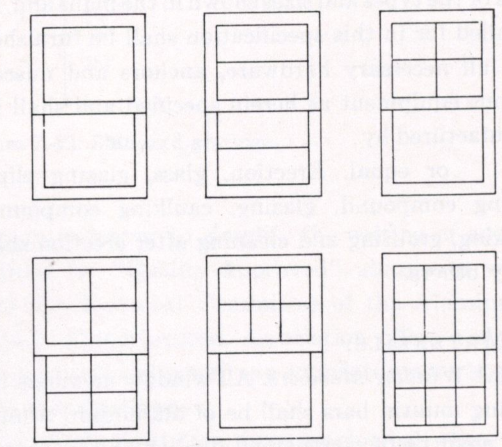
1.2 MATERIALS:

1.2.1 *Window Members.* All window members including muntin bars shall be of aluminum. Aluminum shall be of commercial quality and of proper alloy for window construction, free from defects impairing strength and/or durability. The aluminum alloy used shall contain not more than 0.4 percent copper. Reinforcing members, if used, shall be of aluminum or non-magnetic stainless steel. Material thickness for aluminum members shall be such as to adequately perform the functions for which they are designed.

1.2.2 *Fasteners.* Screws, nuts, washers, bolts,



MODULAR SIZES



MUNTIN ARRANGEMENTS

Figure 7-51: Modular sizes and muntin arrangements of residential type double-hung windows.

rivets and other miscellaneous fastening devices incorporated in the windows shall be of aluminum, non-magnetic stainless steel or other non-corrosive materials compatible with aluminum and shall be of sufficient strength to perform the functions for which they are used. Plated or coated materials are not permitted.

1.2.3 *Hardware.* Hardware having component parts which are exposed shall be of aluminum, non-magnetic stainless steel or other non-corrosive materials compatible with aluminum and shall be of sufficient strength to perform the functions for which it is used. Plated or coated materials not compatible with aluminum are not permitted unless properly insulated from the aluminum.

1.2.4 *Weatherstrip.* Weatherstrip where used shall be of material which is compatible with aluminum.

1.2.5 *Moving Parts.* There shall be no aluminum-to-aluminum contact between hardware parts or window members which are required to move relative to one another and at the same time remain in contact.

1.2.6 *Anchors.* All anchoring devices used in the erection of the windows shall be of aluminum, non-magnetic stainless steel or other non-corrosive materials compatible with aluminum. Steel anchors may be used provided that they are insulated properly from the aluminum.

1.3 CONSTRUCTION:

1.3.1 *Assembly.* The windows shall be assembled in a secure and workmanlike manner to perform as hereinafter specified and to assure neat, weather-tight construction. A permanent watertight joint shall be made at the junction of the sill and side-frame members. Individual windows having ventilating units shall be completely assembled at the plant of the manufacturer ready for shipment as a unit, except that muntin installation may be at the factory or in the field. When welding flux is used, it shall be completely removed immediately upon completion of the welding operation.

1.3.2 *Hardware.* The hardware shall be designed to perform the functions for which it is intended and shall be securely attached to the window.

1.3.3 *Mullions.* Where multiple-unit openings occur, the individual window units shall be joined together with the manufacturer's standard vertical mullion. Where special vertical or horizontal mullions are required for architectural or structural

reasons, they shall be furnished by others unless otherwise specified.

1.3.4 *Glazing.* Windows shall be designed for glazing with ⅛-inch glass unless otherwise specified. Adequate provision shall be made for use of glazing compound and, if specified, glazing beads of any material compatible with aluminum.

1.4 FINISH: The exposed surfaces of all aluminum members shall be cleaned to make them reasonably uniform in color and free from serious surface blemishes. If exposed welded joints are used, they shall be dressed flush and finished to match adjacent surfaces.

1.5 PROTECTIVE COATING:

1.5.1 *Windows.* A suitable protective coating shall be applied to all frame and sash members after fabrication. This applied coating on the aluminum surface must be such as to withstand the action of lime mortar for a period of at least one month in an atmosphere of 100 percent relative humidity at room temperature. The coating used shall be of a type to which the glazing compound will adhere. The preferred coating is a clear water-white methacrylate type lacquer, resistant to alkaline mortar and plaster. Before application of the protective coating the manufacturer shall remove all fabrication compounds, dirt accumulations and/or steel wool fibers deposited by abrasion cleaning.

1.5.2 *Sub-Frames.* If steel sub-frames are used, all surfaces of the steel shall be insulated from direct contact with aluminum surfaces by a heavy coat of an alkali-resistant bituminous paint or a zinc-chromate primer coat or other coating suitable for this purpose. If wood sub-frames are used, the wood shall be properly treated with a preservative which will not promote corrosion of the aluminum. No part of the steel or wood sub-frame shall be left exposed on exterior of building.

1.6 AIR INFILTRATION: The manufacturer shall, when requested, furnish photostatic copies of a test made on a window identical in construction with windows being furnished under this specification. The test shall be made by a recognized testing laboratory showing that air infiltration did not exceed the applicable maximum limit as specified in Section 2 below. The amount of air infiltration shall be measured in terms of cubic feet per minute per foot of crack length when the window is subjected to a static air pressure equal to the pressure exerted by wind at a velocity of 25 miles per hour.

1.7 SCREENS: Screens, where called for, shall be of manufacturer's standard design, have aluminum or non-magnetic stainless steel frames and be wired with 16 x 16 or 18 x 14 mesh aluminum wire cloth. The screen spline shall be aluminum or other suitable material compatible with aluminum. Assembly of the screens shall be in accordance with the construction standards set forth above. Suitable securing devices shall be furnished.

1.8 DRAWINGS AND INSTALLATION DETAILS: The window manufacturer shall furnish standard details showing recommendations for the installation of the windows.

1.9 ERECTION: The erection contractor shall securely anchor windows in place to a straight, plumb and level condition, without distortion of the windows and shall make final adjustment for proper operation of ventilating units after glazing.

1.10 CAULKING: Windows shall be properly caulked by others with a suitable compound to accomplish a thoroughly weathertight installation around the perimeter of the window frame and wall opening.

1.11 GLAZING: The glazing contractor shall furnish a glazing compound which shall have a composition particularly adapted for use with aluminum windows and shall not require painting to protect it from drying out or deterioration. Any material to which the glazing compound will not readily adhere shall be removed from the glazing surfaces by the glazing contractor. If a methacrylate type lacquer has been applied as the protective coating, it need not be removed. Glazing clips, or glazing beads if specified, shall be used with the glazing compound.

The glass shall rest upon shims installed in accordance with accepted glazing procedure so that it will not rest upon any aluminum member.

1.12 Cleaning After Erection: All exposed portions of the windows shall be cleaned by others after the painting and finishing of the building is completed.

Note: To complete the specification add here one or more portions of Section 2.

Section 2: *This section contains the specific requirements applicable to particular types and classes of aluminum windows, and is to be used in conjunction with Section 1.*

Specification DH-A1: Double-Hung (and Single-Hung) Windows for Residential Type Buildings. *Section 1 in its entirety is a part of this specification.*

2.1.1 Materials: Main frame and sash members shall be not less than 0.062-inch in thickness.

2.1.2 Construction: 2.1.2.1 Cut-outs to give access to the sash balances shall be neat and closely fitted. Meeting rails shall contact tightly with each other or with weatherstrips and with wedge blocks at jambs when closed.

2.1.2.2 Where single-hung windows are specified they shall meet all provisions applying to double-hung windows except that only one sash shall be required to operate.

2.1.3 Hardware: The windows shall be equipped with locks and lifts of suitable non-ferrous or non-magnetic stainless steel materials. Sash shall operate freely and be equipped with balancing mechanisms or other devices which will hold both sash stationary at any open position. The mechanisms used shall be easily accessible. Balances shall be installed in the plant of the manufacturer.

2.1.4 Performance Requirements:

2.1.4.1 *Physical Load Tests: Note: Sample submitted for Physical Load Test shall be of manufacturer's largest standard size, of standard construction, and at least 3 feet wide by 5 feet high.*

A.—Horizontal Load Test. A concentrated load of 20 pounds, acting horizontally and applied at the center of the span of any horizontal sash rail assembled in the sash, shall not cause, before the sash are glazed, a horizontal deflection of more than 1/175 of its span and in no case shall the deflection exceed .219-inch.

B.—Vertical Load Test. A concentrated load of 20 pounds, acting vertically and applied at the center of the span of any horizontal rail assembled in the sash, shall not cause, before the sash are glazed, a vertical deflection of more than 1/375 of its span and in no case shall the deflection exceed .094-inch.

C.—Uniform Load Test. Under an exterior uniform load of 10 pounds per square foot no member in completely assembled window without muntins, glazed, closed and locked, continuously supported around its outside perimeter and securely anchored, shall deflect more than 1/175 of its span. *Note: The span length of any horizontal sash member shall be considered as equal to the overall width of the sash provided for that size of window.*

2.1.4.2 *Air Infiltration Test.* When tested in accordance with the procedure as outlined in Section 1 under Air Infiltration, the air infiltration shall not exceed ¾ cubic foot per minute per foot of crack length with sash in closed position and locked. The sash shall have been adjusted to operate in either direction with a force not exceeding 20 pounds after the sash is in motion. The nominal size of the window tested shall be 3 feet wide by 5 feet high or have a frame and integral sash perimeter equal thereto.

Manufacturers: The following companies manufacture a DH-A1 type window which meets these specifications and are eligible to display the "Quality-Approved" Seal. Ceco Steel Products Corporation (*Sterling Aluminum Window Division*), 5601 West 26th St., Chicago 50, Ill. (*Series 50-B*). Cupples Products Corp., 2650 So. Hanley Road, Maplewood, St. Louis 17, Mo. (*Series 200-B*). Michael Flynn Mfg. Co., 700 East Godfrey Ave., Philadelphia 24, Pa. (*Lupton DH*). General Bronze Corporation (*Alwintite Division*), Stewart Ave., Garden City,

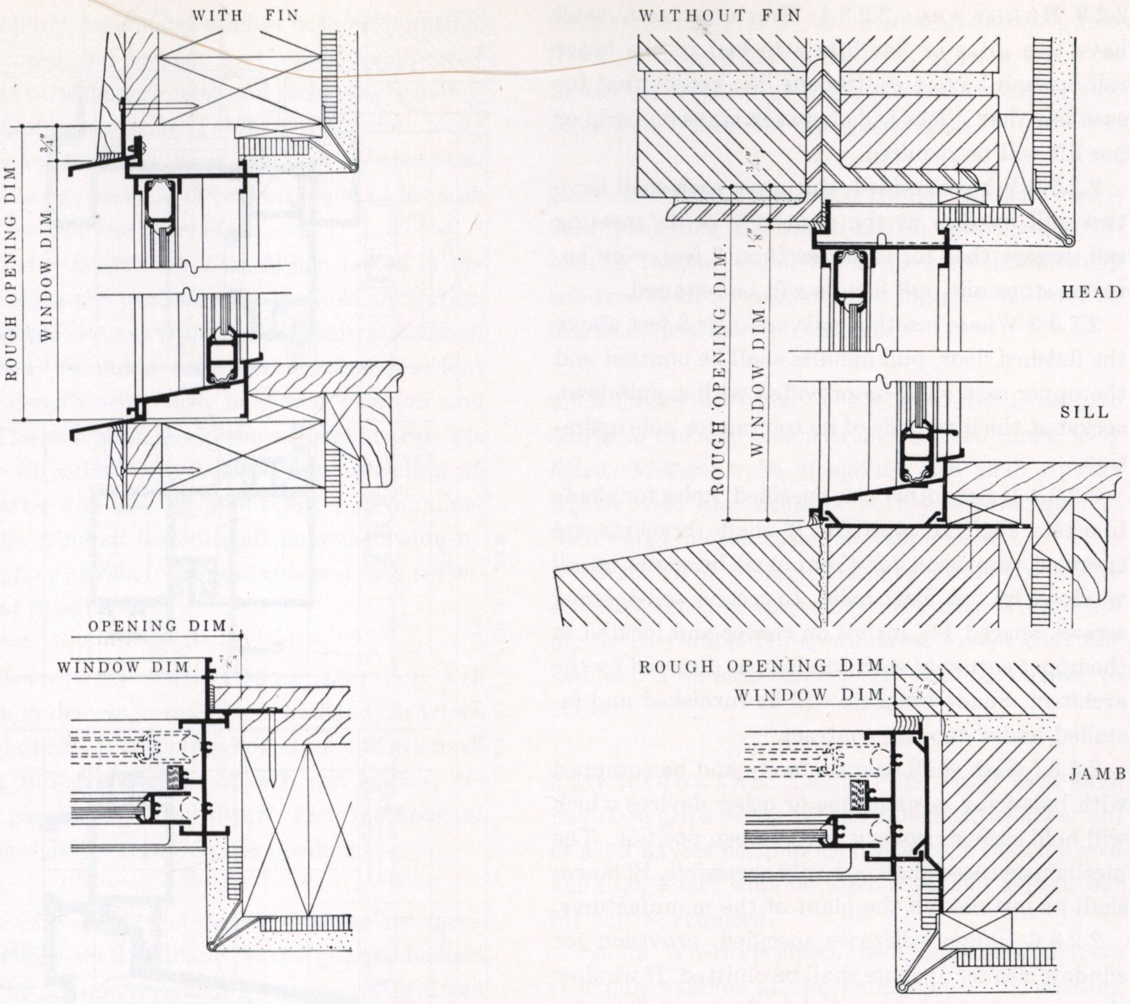


Figure 7-52: Typical double-hung window installations for residential type buildings with and without fins.

N. Y. (*Alwintite, Series DHA-O*). Luria Building Products, Inc. Box 27, Bristol, Pa. (*Series 60*). Metal Arts Mfg. Co., Inc., Harwell & Oakcliff Rd., Atlanta, Ga. (*Metalart, Series 100-E*). J. S. Thorn Co., 8501 Hegerman St. Philadelphia 36, Pa. (*Series A-200*). Windalume Corporation, Route 46, Kenvil, N. J. (*Series 100*).

SPECIFICATION DH-A2: DOUBLE-HUNG (AND SINGLE AND TRIPLE-HUNG) WINDOWS FOR COMMERCIAL TYPE BUILDINGS. *Section 1 in its entirety is a part of this specification.*

2.2.1 MATERIALS: Main frame and sash members (excluding sills) shall not be less than 0.062-inch in thickness. Sill members not reinforced by subframes or by proper stiffening ribs shall not be less than .078-inch in thickness.

2.2.2 CONSTRUCTION: 2.2.2.1 Cut-outs to give access to the sash balances shall be neat and closely fitted. Meeting rails of sliding sash shall contact tightly with each other or with weatherstrips and with wedge blocks at jambs when closed.

2.2.2.2 Where single-hung or triple-hung windows are specified they shall meet all provisions applying to double-hung windows except that one sash and three sash respectively shall be required to operate.

2.2.3 Hardware: 2.2.3.1 The lower sash shall have two grips or bar lifts attached to the lower rail or shall have a continuous lift, except that for sash less than 3 feet wide between stops one grip or bar lift will be required.

2.2.3.2 When specified, the upper sash shall have two pull handles at the underside of its meeting rail, except that for sash less than 3 feet wide between stops one pull handle will be required.

2.2.3.3 Where meeting rails are over 6 feet above the finished floor, pull handles shall be omitted and the upper sash shall be provided with a pull-down socket at the inner side of its top rail for pole operation.

2.2.3.4 Unless otherwise specified, holes for shade brackets shall be omitted. If shade brackets are specified, provision for them shall be made on all windows by two clear holes, to receive self-tapping screws, spaced $1\frac{1}{4}$ inches on center and located in the upper corner of each window, as directed by the architect. Shade brackets will be furnished and installed under another contract.

2.2.3.5 Sash shall operate freely and be equipped with balancing mechanisms or other devices which will hold sash stationary at any open position. The mechanisms used shall be easily accessible. Balances shall be installed in the plant of the manufacturer.

2.2.3.6 Unless otherwise specified, provision for window cleaner anchors shall be omitted. If window cleaner anchors are specified to be secured to the window frame, the frame shall be reinforced as may be required to receive the window cleaner anchors, and the window frames shall be anchored securely to the wall construction at the point of application of the window cleaner bolts.

2.2.4 Performance Requirements:

2.2.4.1. *Physical Load Tests. Note: Sample submitted for Physical Load Tests shall be of manufacturer's largest standard size, of standard construction, and at least 4 feet 6 inches wide by 7 feet 6 inches high.*

A.—Horizontal Load Test. A concentrated load of 30 pounds, acting horizontally and applied at the center of the span of any horizontal sash rail, shall not cause, before the sash are glazed, a horizontal

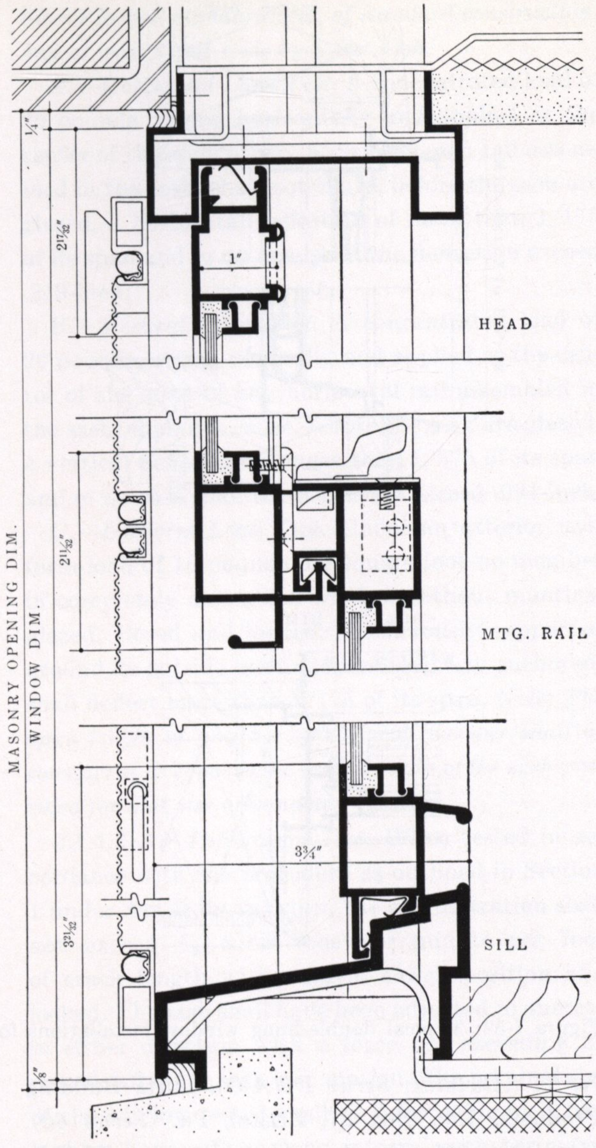


Figure 7-53: Typical double-hung commercial type window installation.

deflection of more than 1/175 of its span and in no case shall the deflection exceed .250-inch.

B.—Vertical Load Test. A concentrated load of 30 pounds, acting vertically and applied at the center of the span of any horizontal sash rail, shall not cause, before the sash are glazed, a vertical deflection of more than 1/375 of its span and in no case shall the deflection exceed .160 inches.

C.—Uniform Load Test. Under an exterior uniform load of 15 pounds per square foot, no member

in a completely assembled window without muntins, glazed, closed and locked, continuously supported around its outside perimeter and securely anchored, shall deflect more than 1/175 of its span. *Note: The span length of any horizontal sash member shall be considered as equal to the overall width of the sash provided for that size of window.*

2.2.4.2 *Air Infiltration Test.* When tested in accordance with the procedure as outlined in Section 1 under AIR INFILTRATION, the air infiltration shall not exceed ½ cubic foot per minute per foot of crack length with sash in closed position and locked. The sash shall have been adjusted to operate in either direction with a force not exceeding 35 pounds after the sash is in motion. The nominal size of the window tested shall be 4 feet wide by 6 feet high or have a frame and integral sash perimeter equal thereto.

2.2.5 DRAWINGS AND INSTALLATION DETAILS: Shop drawings shall be submitted, in triplicate, for approval. Drawings will show elevations of windows, full-size sections of sash and frames, details of construction, hardware and methods of anchoring window frame in the opening.

2.2.6 GLAZING: If bead glazed windows are specified, provision shall be made for the glass to be held in place by aluminum glazing beads, neatly fitted and securely attached to the sash members, and so designed that the glass may be bedded in glazing compound on both sides of the glass.

Manufacturers: The following companies manufacture a DH-A2 type window which meets these specifications and are eligible to display the "Quality-Approved" Seal. Ceco Steel Products Corporation (*Sterling Aluminum Window Division*), 5601 West 26th St., Chicago 50, Ill. (*Series 150-B and 200-B*). Cupples Products Corp., 2650 So. Hanley Road, Maplewood, St. Louis 17, Mo. (*Series 490 and 30*). General Bronze Corp., Stewart Ave., Garden City, N. Y. (*Permatite, Series DHA-3*). Luria Building Products, Inc., Box 27, Bristol, Pa. (*Series 100*). J. S. Thorn Co., 8501 Hegerman St. Philadelphia 36, Pa. (*Series A-500*). Windalume Corporation, Route 46, Kenvil, N. J. (*Series 200*).

SPECIFICATION DH-A3: DOUBLE-HUNG (AND SINGLE AND TRIPLE-HUNG) WINDOWS FOR MONUMENTAL TYPE BUILDINGS: *Section 1 in its entirety is a part of this specification.*

2.3.1. MATERIALS: Main frame and sash members (excluding sills) shall not be less than 0.062-inch in thickness. Sill members not reinforced by sub-frames or by proper stiffening ribs shall not be less than .094-inch in thickness.

2.3.2 CONSTRUCTION: 2.3.2.1 Cut-outs to give access to the sash balances shall be neat and closely fitted. Meeting rails of sliding sash shall contact tightly with each other or with weatherstrips and with wedge blocks at jambs when closed.

2.3.2.2. Where Single-Hung or Triple-Hung windows are specified they shall meet all provisions applying to Double-Hung windows, except that one sash and three sash respectively shall be required to operate.

2.3.3 HARDWARE: 2.3.3.1 The lower sash shall have two grips or bar lifts attached to the lower rail or shall have a continuous lift, except that for sash less than 3 feet wide between stops one grip or bar lift will be required.

2.3.3.2 Where specified, the upper sash shall have two pull handles at the underside of its meeting rail, except that for sash less than 3 feet wide between stops one pull handle will be required.

2.3.3.3 Where meeting rails are over 6 feet above the finished floor, pull handles shall be omitted and the upper sash shall be provided with a pull-down socket at the inner side of its top rail for pole operation.

2.3.3.4 Unless otherwise specified, holes for shade brackets shall be omitted. If shade brackets are specified, provision for them shall be made on all windows by two clear holes, to receive self-tapping screws, spaced 1¼ inches on center and located in the upper corner of each window, as directed by the architect. Shade brackets will be furnished and installed under another contract.

2.3.3.5 Sash shall operate freely and be equipped with balancing mechanisms or other devices which

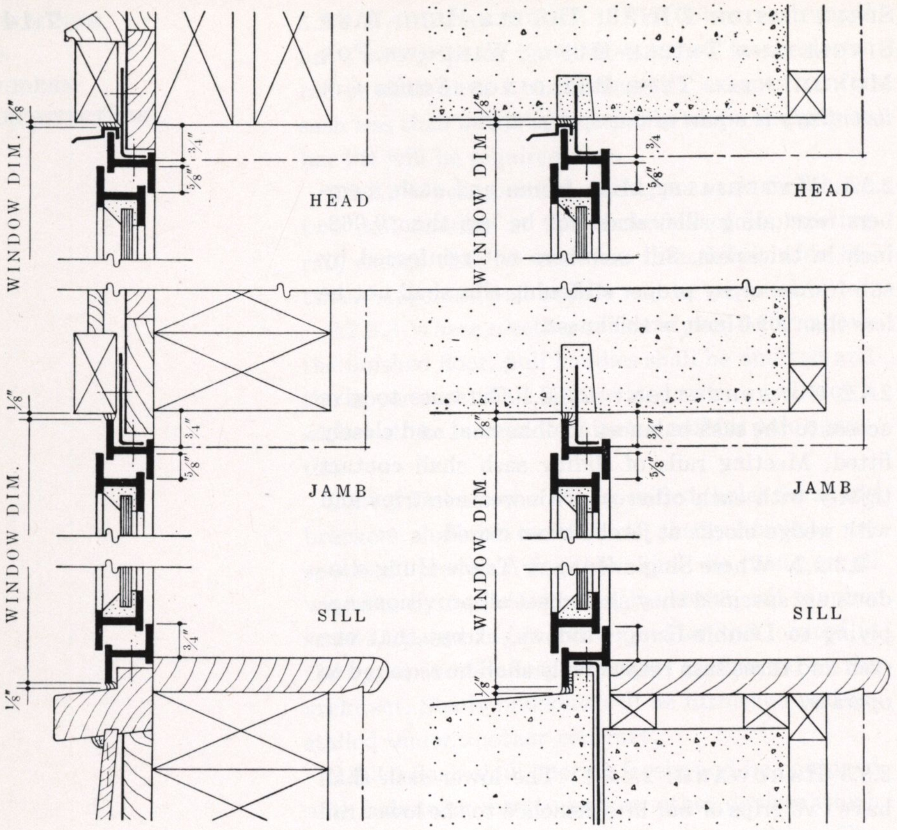


Figure 7-54: Typical installations with fin.

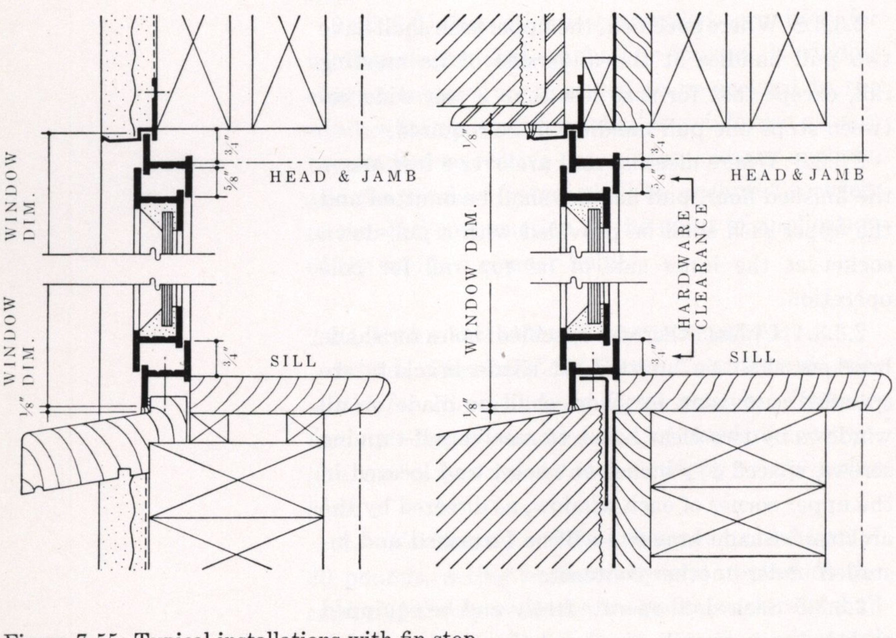


Figure 7-55: Typical installations with fin stop.

will hold sash stationary at any open position. The mechanisms used shall be easily accessible. Balances shall be installed in the plant of the manufacturer.

2.3.3.6 Unless otherwise specified, provision for window cleaner anchors shall be omitted. If window cleaner anchors are specified to be secured to the window frame, the frame shall be reinforced as may be required to receive the window cleaner anchors, and the window frames shall be anchored securely to the wall construction at point of application of the window cleaner bolts.

2.3.4 PERFORMANCE REQUIREMENTS:

2.3.4.1 *Physical Load Tests. Note: Sample submitted for Physical Load Tests shall be of manufacturer's largest standard size, of standard construction, and at least 5 feet 6 inches wide by 10 feet high.*

A.—Horizontal Load Test. A concentrated load of 40 pounds, acting horizontally and applied at the center of the span of any horizontal sash rail, shall not cause, before the sash are glazed, a horizontal deflection of more than 1/175 of its span and in no case shall the deflection exceed .312-inch.

B.—Vertical Load Test. A concentrated load of 40 pounds, acting vertically and applied at the center of the span of any horizontal sash rail, shall not cause, before the sash are glazed, a vertical deflection of more than 1/375 of its span and in no case shall the deflection exceed .188-inch.

C.—Uniform Load Test. Under a minimum exterior uniform load of 15 pounds per square foot no member in a completely assembled window without muntins, glazed, closed and locked, continuously supported around its outside perimeter and securely anchored, shall deflect more than 1/175 of its span. *Note: The span length of any horizontal sash member shall be considered as equal to the overall width of the sash provided for that size of window.*

2.3.4.2 *Air Infiltration Test.* When tested in accordance with the procedure as outlined in Section 1 under AIR INFILTRATION, the air infiltration shall not exceed ½ cubic foot per minute per foot of crack length with sash in closed position and locked. The sash shall have been adjusted to operate in either direction with a force not exceeding 45 pounds after the sash is in motion. The

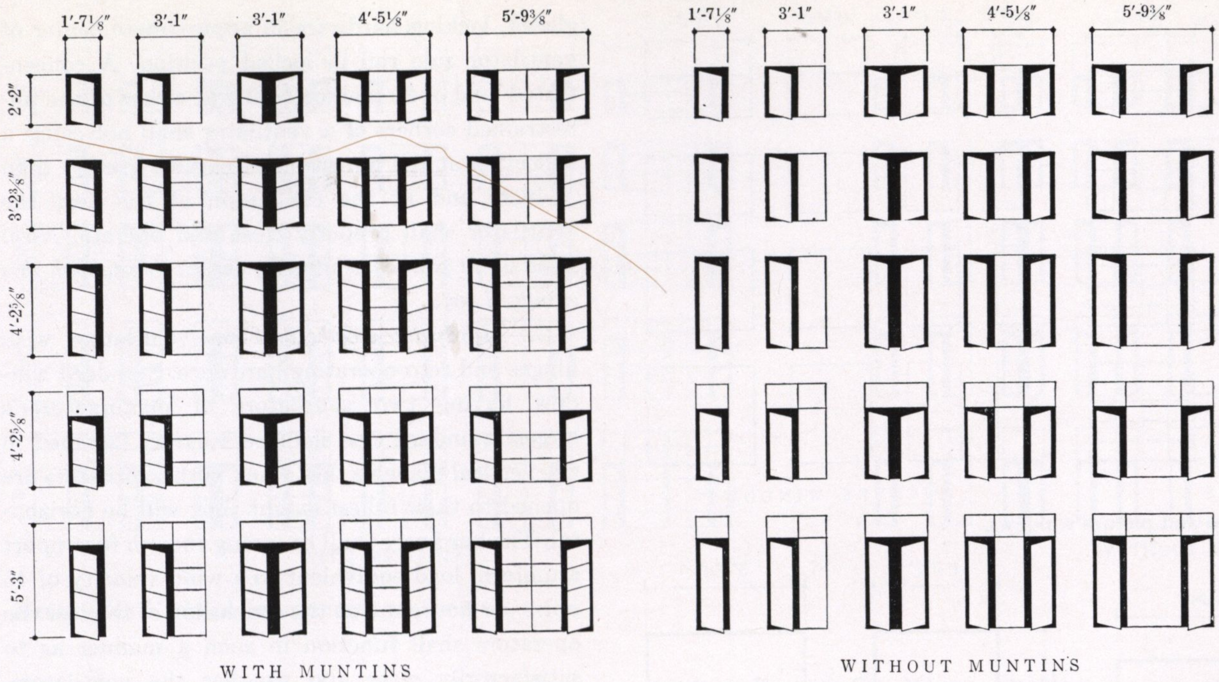


Figure 7-56: Standard size casement windows.

nominal size of the window tested shall be 4 feet wide by 6 feet high or have a frame and integral sash perimeter equal thereto.

2.3.5 DRAWINGS AND INSTALLATION DETAILS: Shop drawings shall be submitted in triplicate, for approval. Drawings shall show elevations of windows, full-size sections of sash and frames, details of construction, hardware and methods of anchoring window frame in the opening.

2.3.6 GLAZING: If bead glazed windows are specified, provision shall be made for the glass to be held in place by aluminum glazing beads, neatly fitted and securely attached to the sash members, and so constructed that the glass may be bedded in glazing compound on both sides of the glass.

Manufacturers: The following companies manufacture a DH-A3 type window which meets these specifications and are eligible to display the "Quality-Approved" Seal. Ceco Steel Products Corporation (*Sterling Aluminum Window Division*) 5601 West 26th St., Chicago 50, Ill. (*Series 200-B*). Cupples Products Corp., 2650 So. Hanley Road, Maplewood, St. Louis 17, Mo. (*Series 500 and 495*). General Bronze Corp., Stewart Ave., Garden City, N. Y. (*Permatite, Series DHA-3 and DHA-5*). J. S. Thorn Co., 8501 Hegerman St., Philadelphia 36, Pa. (*Series A-5000*). Windalume Corporation, Route 46, Kenvil, N. J. (*Series 300 and 350*).

SPECIFICATION C-A1: CASEMENT WINDOWS FOR RESIDENTIAL TYPE BUILDINGS: *Section 1 in its entirety is a part of this specification.*

2.4.1 MATERIALS: Main frame and sash members shall not be less than .062-inch in thickness. Detached hardware and hinges having component parts which are exposed shall be aluminum, non-magnetic stainless steel or other non-corrosive materials which are compatible with aluminum and of sufficient strength to perform the functions for which they are used. Plated or coated materials not compatible with aluminum are not permitted unless properly insulated from the aluminum.

2.4.2 HARDWARE: Satisfactory hardware shall be provided to control and securely lock the operating units. Extension hinges, locking handles and roto

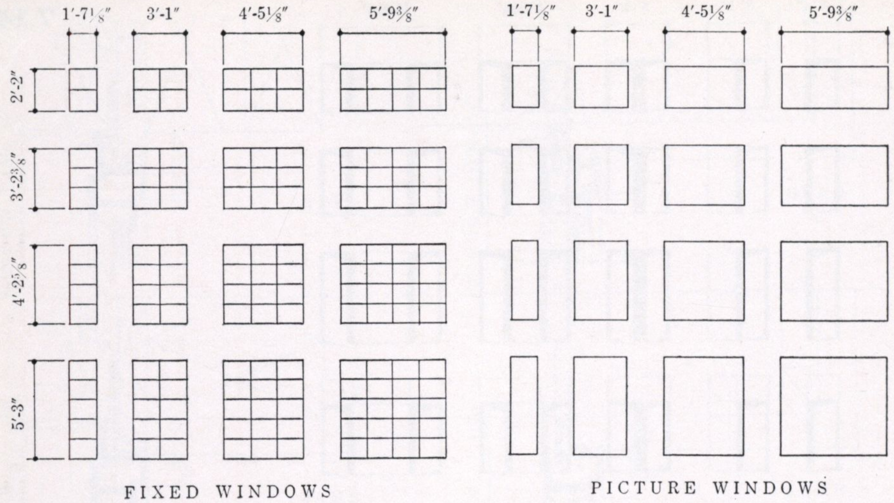


Figure 7-57: Standard size fixed and picture windows.

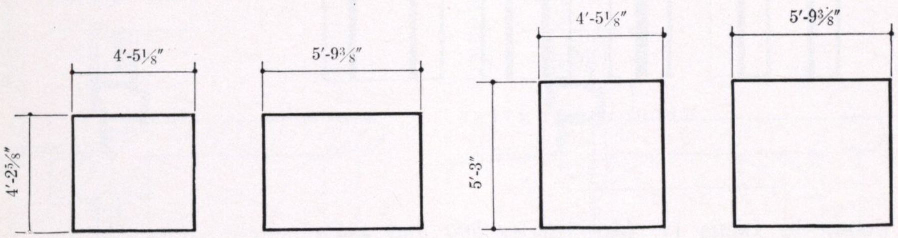


Figure 7-58: Standard double insulating windows.

type operators shall be furnished unless otherwise specified.

2.4.3 Performance Requirements:

2.4.3.1 *Physical Load Tests. Note: Sample submitted for Physical Load Tests shall be of standard construction containing outswinging ventilators of manufacturer's largest standard size, at least 5 feet 9 inches wide by 5 feet 3 inches high.*

A.—Vertical Deflection Test of completely assembled window, ventilator without muntins, unglazed, with manufacturer's standard hardware. A concentrated load of 45 pounds, acting at the lower unrestrained corner of a ventilator opened 90° shall not cause a vertical deflection at the lower unrestrained corner greater than ½-inch, and at the conclusion of the test the ventilator shall properly close and operate. *Note: Load of 45 pounds arbitrarily chosen to establish this standard test.*

B.—Horizontal Deflection Test on ventilator installed in window frame, without muntins, unglazed, locking hardware in approximate center of ventilator side rail in locked position. A concentrated load of 20 pounds acting at either of the unrestrained corners of a ventilator shall not cause a deflection at the unrestrained corners greater than ⅜-inch, and at the conclusion of the test the ventilator shall properly close and operate. *Note: Load of 20 pounds arbitrarily chosen to establish this standard test.*

C.—Hardware Load Test on ventilators with hinges and roto-operating hardware. Standard window having two ventilators of manufacturer's largest standard size shall be securely fastened in the vertical plane so that when both ventilators are opened to their fullest extent they will be horizontal. The hardware shall be strong enough to support a uniform load equivalent to a wind velocity of 45 miles per hour, and at the conclusion of the test the operators shall function in such a manner as to satisfactorily close and weather the ventilators. There shall be no failure of screws, track or permanent deformation of arm allowed.

D.—Uniform Load Test on single and multiple window openings, glazed, closed and locked, supported continuously around outside perimeter and securely anchored. When subjected to an exterior uniform load of 10 pounds per square foot:

a. No member in a single window unit, including those consisting of a combination of vents, fixed side lights and/or transoms, shall deflect more than 1/175 of its span. Window tested shall be manufacturer's largest standard size.
b. No member, including horizontal and vertical mullions connecting single window units into multiple openings, shall deflect more than 1/175 of its span. All members in single units so combined must meet test described in paragraph (a) immediately above.

2.4.3.2 *Air Infiltration Test:* When tested in accordance with the procedure as outlined in Section 1 under Air Infiltration, the air infiltration shall not exceed one cubic foot per minute per foot of crack length with ventilator in closed position and locked for non-weatherstripped windows; ½ cubic foot for weatherstripped. The window tested shall have a nominal size of 3 feet x 4 feet and shall have

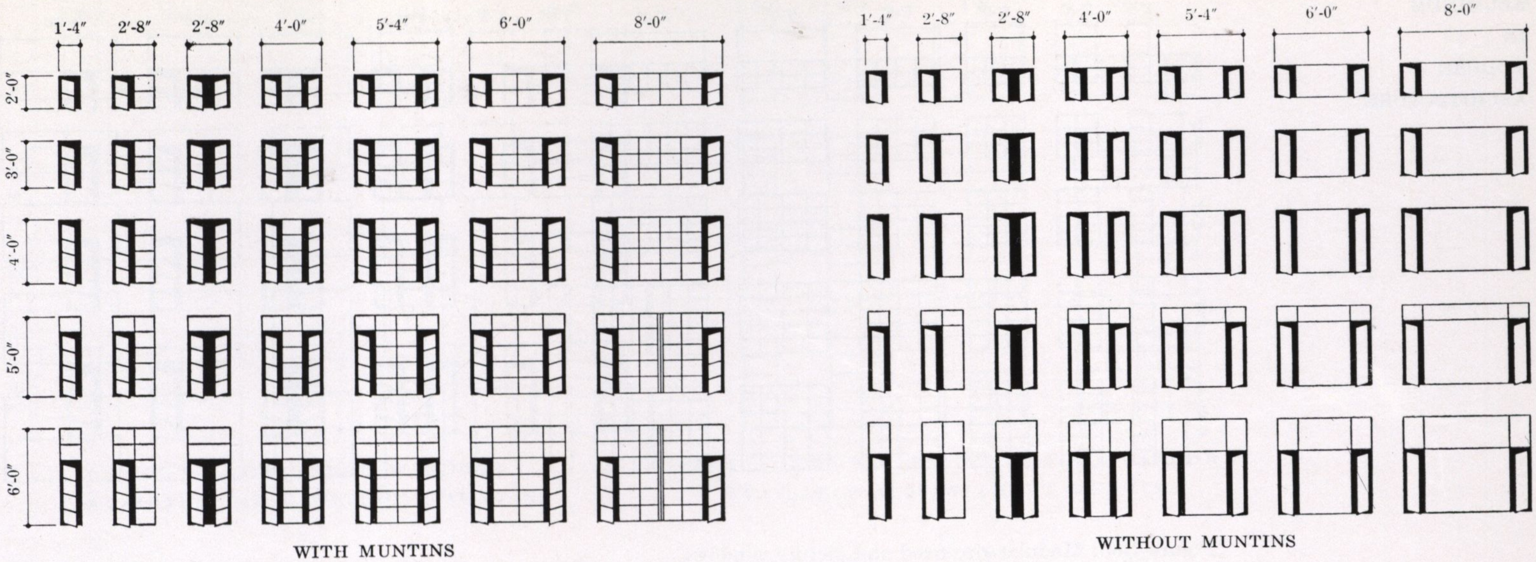


Figure 7-59: Modular size casement windows.

two ventilators, each 1 foot 6 inches x 4 foot.

2.4.4 HOPPER AND TRANSOM VENTILATORS: When used in combination with side-hinged ventilators as covered by this specification, hopper and/or transom ventilators shall be correlated with the provisions of Specification P-A1.

Manufacturers: The following companies manufacture a C-A1 type window which meets these specifications and are eligible to display the "Quality-Approved" Seal. Alcasco Products, Inc., 12640 Burt Road, Detroit, Mich. (*Series C-9 Casements*). Bourne Products Inc., 900 Bourne Place, El Cajon, Calif. (*Dual-Fin*). Ceco Steel Products Corporation (*Sterling Aluminum Window Division*), 5601 West 26th St., Chicago 50, Ill. (*Series 800*). Duralite Window Corp., Carr St. & Southern, Knoxville, Tenn. Fentron Industries, Inc., 2801 MarketSt., Seattle 7, Wash. (*Series 30-Casement*). Michael Flynn Mfg. Co., 700 East Godfrey Ave., Philadelphia 24, Pennsylvania. (*Lupton Residential Casement.*) Reynolds Metals Co. (*Window Division*), 2000 S. 9th St., Louisville, Ky. (*Series 3000 Residential Casement*) J. S. Thorn Co., 8501 Hegerman St., Philadelphia 36, Pennsylvania. (*Series A-100, A-104, A-105*). Universal Window Co., 950 ParkerSt., Berkeley 10, California. (*Series C-100*). Ware Laboratories, Inc., 3700 N. W. 25th St., Miami, Florida.

SPECIFICATION C-A2: CASEMENT WINDOWS FOR COMMERCIAL TYPE BUILDINGS: *Section 1 in its entirety is a part of this specification.*

2.5.1 MATERIALS: Main frame and sash members, including sills, shall not be less than .062-inch in thickness. Detached hardware, including hinges or sliding shoes, having component parts which are exposed, shall be of aluminum, non-magnetic stainless steel or other non-corrosive materials which are compatible with aluminum and of sufficient strength to perform the functions for which they are used. Bronze hardware may be used provided that it has a heavy deposit of chrome plate and is properly insulated from direct contact with the aluminum.

2.5.2 HARDWARE: Satisfactory hardware shall be provided to control and securely lock the ventilators. Extension hinges or sliding type pivots, locking handles and roto type operators shall be furnished unless otherwise specified.

2.5.3 PERFORMANCE REQUIREMENTS:

2.5.3.1 *Physical Load Tests. Note: Sample submitted for Physical Load Test shall be of standard*

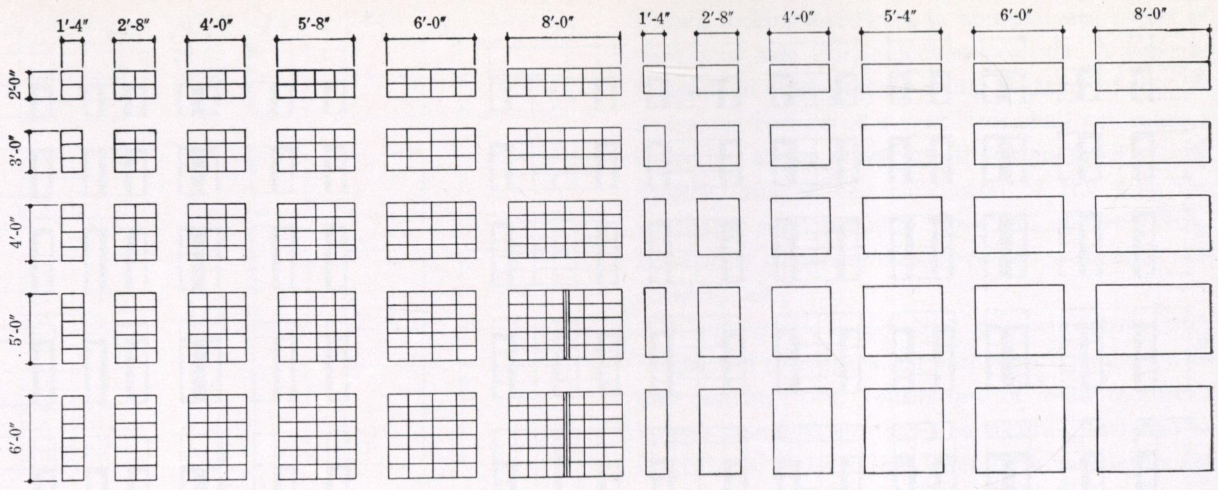


Figure 7-60: Modular size fixed and picture windows.

construction containing outswinging ventilators of manufacturer's largest standard size.

A.—Vertical Deflection Test of completely assembled window, ventilator without muntins, unglazed, with manufacturer's standard hardware. A concentrated load of 60 pounds, acting at the lower unrestrained corner of a ventilator opened 90° shall not cause a vertical deflection at the lower unrestrained corner greater than 5/16-inch, and at the conclusion of the test the ventilator shall properly close and operate. *Note: Load of 60 pounds arbitrarily chosen to establish this standard test.*

B.—Horizontal Deflection Test on ventilator installed in window frame, without muntins, unglazed, locking hardware in approximate center of ventilator side rail in locked position. A concentrated load of 20 pounds acting at either of the unrestrained corners of a ventilator shall not cause a deflection at the unrestrained corners greater than 5/16-inch, and at the conclusion of the test the ventilator shall properly close and operate. *Note: Load of 20 pounds arbitrarily chosen to establish this standard test.*

C.—Hardware Load Test on ventilator with hinges and roto operating hardware. Standard window having two ventilators of manufacturer's largest standard size shall be securely fastened in the vertical plane so that when both ventilators are opened to their fullest extent they will be horizontal. The hardware shall be strong enough to support a uniform load equivalent to a wind velocity of 50 miles per hour, and at the conclusion of the test the operators shall function in such a manner as to satisfactorily close and weather the ventilators. No failure of screws or track nor any permanent deformation of arm shall be allowed.

D.—Uniform Load Test on unit consisting of frame and pair of ventilating sash, glazed, closed and locked. This unit, which shall be manufacturer's largest standard size, is to be continuously supported around the outside perimeter and securely anchored. When subjected to a minimum exterior uniform load of 15 pounds per square foot, no member in this unit shall deflect more than 1/175 of its span. *Note: Due to the great variation of design and arrangements of ventilating units required by windows of this type and class, this uniform load test cannot be performed except on a standard unit such as that specified above. In order to ensure uniformity of strength of all members required in any type of multiple unit opening, the manufacturer shall guarantee the use of a design for mullions, transom bars and other connecting members that will not permit a deflection greater than 1/175 of the span of any member under conditions simulating the load test described immediately above.*

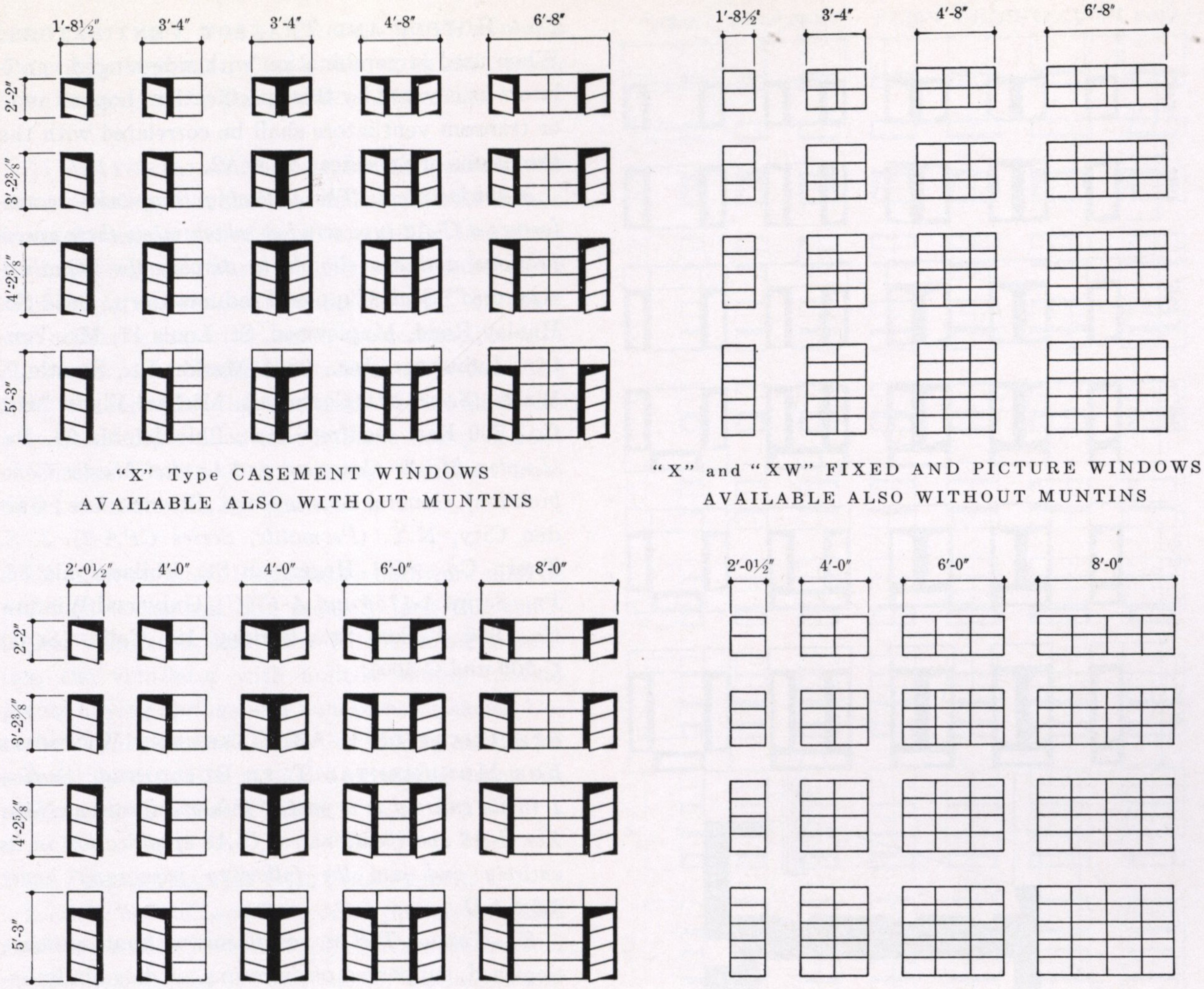


Figure 7-61: "X" and "XW" casement and picture windows.

2.5.3.2 *Air Infiltration Test*

A.—Windows With Weatherstripping. When tested in accordance with the procedure as outlined in Section 1 under AIR INFILTRATION, the air infiltration shall not exceed ½ cubic foot per minute per foot of crack length with ventilator in closed position and locked. The window tested shall be of a nominal size of 4 feet x 6 feet and shall have two ventilators, each being of a nominal size of 2 feet x 6 feet. Ventilators shall be equipped with metal or other approved type weatherstripping.

B.—Windows Without Weatherstripping. Where windows are specified to be of a design with two-point or three-point metal-to-metal contact without the use of auxiliary weatherstripping the air infiltration, when tested in accordance with the procedure as outlined in Section 1 under AIR INFILTRATION, shall not exceed one cubic foot per minute per foot of crack length with ventilator in closed position and locked. The window tested shall be of a nominal size of 4 feet x 6 feet and shall have two ventilators, each being of a nominal size of 2 feet x 6 feet.

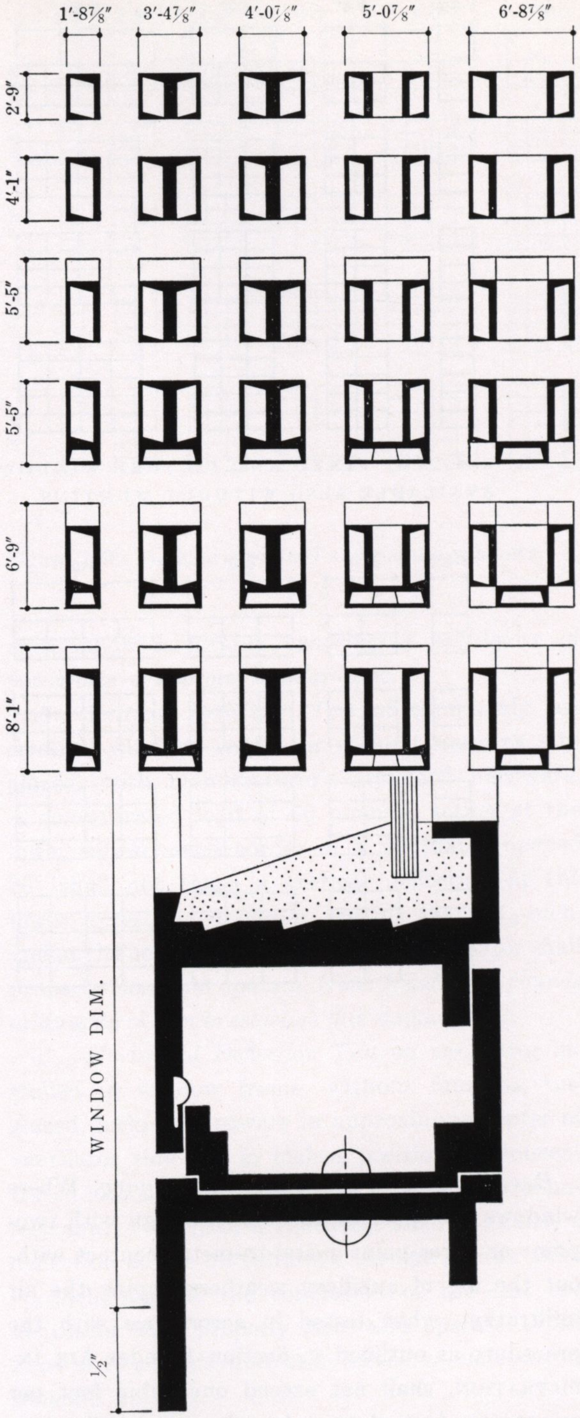


Figure 7-62: Standard casement windows for commercial and monumental type buildings . . . sizes and typical window sections. Dimensions are window opening. Horizontal and/or vertical muntins may be added, based on 20-inch or 24-inch bar centers for width and 16-inch bar centers for height. Fixed light may be provided at sill in place of sill vents. Fixed types furnished for all sizes shown.

2.5.4 Hopper and Transom Ventilators: When used in combination with side-hinged ventilators as covered by this specification, hopper and/or transom ventilators shall be correlated with the provisions of Specification P-A2.

Manufacturers: The following companies manufacture a C-A2 type window which meets these specifications and are eligible to display the "Quality-Approved" Seal. Cupples Products Corp., 2650 So. Hanley Road, Maplewood, St. Louis 17, Mo. Fentron Industries, Inc., 2801 Market St., Seattle 7, Wash. (*Series 310 Casement*). Michael Flynn Mfg. Co., 700 East Godfrey Ave., Philadelphia 24, Pa. (*Lupton Master Casement and Lupton Master Combination*). General Bronze Corp., Stewart Ave., Garden City, N.Y. (*Permatite, Series CPA-2*). J. S. Thorn Co., 8501 Hegerman St., Philadelphia 36, Pa. (*Series A-1755 and A-175C*). Universal Window Co., 950 Parker St., Berkley 10, Calif. (*Series C-300 and C-500*).

Specification C-A3: Casement Windows for Monumental Type Buildings: *Section 1 in its entirety is a part of this specification. Note: For C-A3 specifications use C-A2 specification in its entirety and add the following paragraph under 2.5.3.1-D.*

E.—Torsion Test on ventilator, without muntins, unglazed, supported on fulcrums, at diagonally opposite corners, with the corner diagonally opposite the loaded corner secured in the same plane by fulcrum support block and clamp. A concentrated load of 20 pounds acting at the unrestrained corner of the ventilator shall not cause a deflection at the unrestrained corner greater than 1½ inches. *Note: Load of 20 pounds arbitrarily chosen to establish this standard test.*

Manufacturers: The following companies manufacture a C-A3 type window which meets these specifications and are eligible to display the "Quality-Approved" Seal. Cupples Products Corp., 2650 So. Hanley Road, Maplewood, St. Louis 17, Mo. Fentron Industries, Inc., 2801 Market St., Seattle 7, Wash. (*Series 20-Casement*). General Bronze Corp., Stewart Ave., Garden City, N. Y. (*Permatite, Series CPA-2*).

Specification P-A1: Projected Windows For Residential Type Buildings: *Section 1 in its entirety is a part of this specification.*

2.7.1 Materials: Main frame and sash members, including sills, shall not be less than 0.062-inch in thickness. Detached hardware and sliding shoes having component parts which are exposed shall be aluminum, non-magnetic stainless steel, or other non-corrosive materials which are compatible with aluminum and of sufficient strength to perform the functions for which they are used. Bronze hardware may be used provided that it has a heavy deposit of chrome plate and is properly insulated from direct contact with the aluminum.

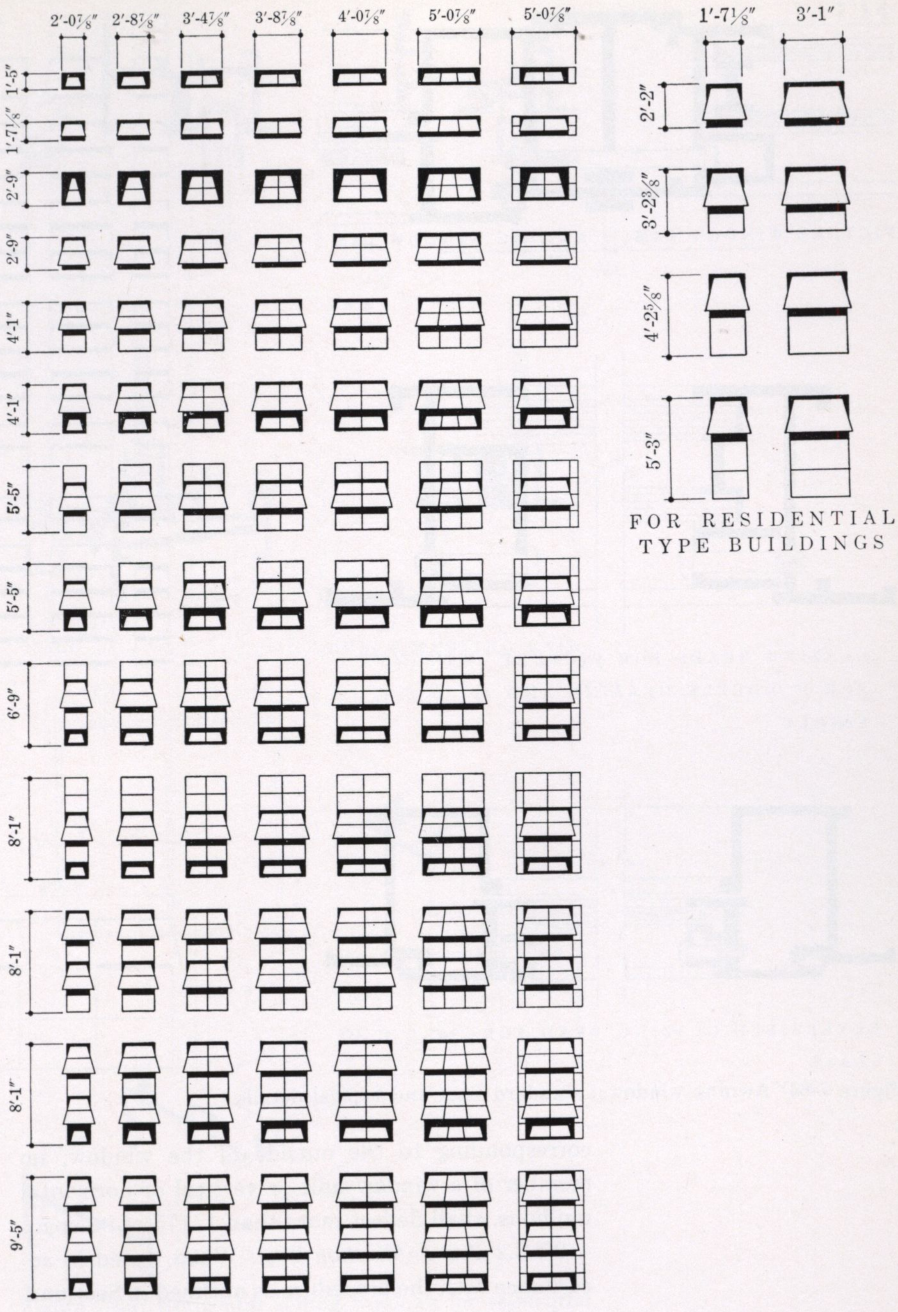
2.7.2 Hardware: Satisfactory hardware shall be provided to control and securely lock the ventilators. Ventilators shall have balance arms to position the ventilator with built-in sliding friction pivots having springs and non-abrasive shoes. Detached hardware shall consist of locking handle for manual operation as standard or spring catch for pole operation where required.

2.7.3 Performance Requirements:

2.7.3.1 *Physical Load Tests. Note: Sample submitted for Physical Load Tests shall be of standard construction containing projected-out ventilator of manufacturers' largest standard size at least 4 feet by 5 feet 9 inches.*

A.—Hardware Load Test on unglazed window with projected-out ventilator open to 45°, securely clamped and continuously supported around the outside perimeter, one free corner of the open ventilator securely held in the 45° position by blocking between the corner of the ventilator and the fixed portion of the window. A concentrated load of 17 pounds acting from the outside, perpendicular to the plane of the fixed portion and applied to the free rail of the ventilator at the point of locking handle attachment, shall not cause a deflection at the free corner opposite the blocked corner, measured perpendicular to plane of the fixed portion, greater than 3½ inches.

B.—Uniform Load Test on complete unit. A glazed window with ventilator closed and locked



FOR RESIDENTIAL TYPE BUILDINGS

FOR COMMERCIAL AND MONUMENTAL TYPE BUILDINGS

Figure 7-63: Standard sizes of projected windows.

shall be continuously supported around the outside perimeter and securely anchored. When subjected to an exterior uniform load of 10 pounds per square foot, applied perpendicular to and on the surface

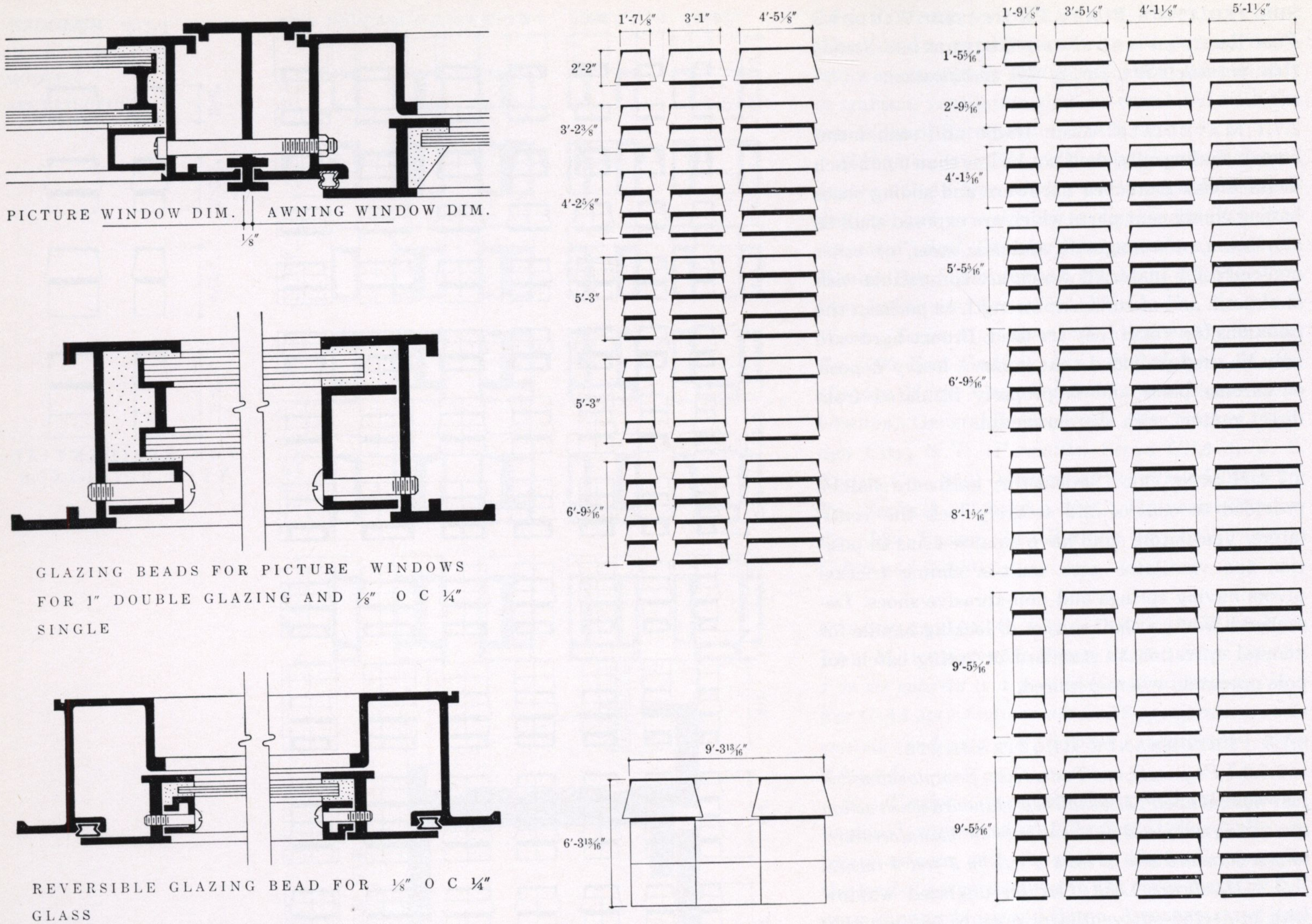


Figure 7-64: Awning windows; standard sizes and typical details.

corresponding to the outside of the window, no member of a window unit or vertical or horizontal mullions, shall deflect more than 1/175 of its span.

2.7.3.2 *Air Infiltration Test:* When tested in accordance with the procedure as outlined in Section 1 under AIR INFILTRATION, the air infiltration shall not exceed one cubic foot per minute per foot of crack length with ventilator in closed position and locked (non-weatherstripped; ½ cubic foot for weatherstripped). The nominal size of the ventilators of the window tested shall be approximately 3 feet wide by 2 feet high.

Manufacturers: The following companies manufacture a P-A1 type window which meets these specifications and are eligible to display the "Quality-Approved" Seal. Bourne Products Inc., 900 Bourne Place, El Cajon, Calif. (*Town & Country Series*). Ceco Steel Products Corp. (*Sterling Aluminum Window Div.*), 5601 West 26th St., Chicago 50, Ill. (*Series 500, 525*). Cupples Products Corp., 2650 So. Hanley Road, Maplewood, St. Louis 17, Mo. (*Series 700*). Fentron Industries, Inc., 2801 Market St., Seattle 7, Wash. (*Series 30-Projected*). Reynolds Metals Co. (*Window Division*), 2000 S. 9th St., Louisville, Ky. (*Series 500 Residen'ial Projected*) J. S. Thorn Co., 8501 Hegerman St., Philadelphia, 36 Pa. Univer-

sal Window Co., 950 Parker St., Berkeley 10, Cal. (*Series A-175P*). Ware Laboratories, Inc., 3700 N.W. 25th St., Miami, Fla.

SPECIFICATION P-A2: PROJECTED WINDOWS FOR COMMERCIAL AND MONUMENTAL TYPE BUILDINGS: *Section 1 in its entirety is a part of this specification.*

2.8.1 MATERIALS: Main frame and sash members, including sills, shall not be less than .062-inch in thickness. Detached hardware and sliding shoes having component parts which are exposed shall be aluminum, non-magnetic stainless steel, or other non-corrosive materials which are compatible with aluminum and of sufficient strength to perform the functions for which they are used. Bronze hardware may be used provided that it has a heavy deposit of chrome plate and is properly insulated from direct contact with the aluminum.

2.8.2 HARDWARE: Satisfactory hardware shall be provided to control and securely lock the ventilators. Ventilators shall have balance arms to position the ventilator with built-in sliding friction pivots having springs and non-abrasive shoes. Detached hardware shall consist of one locking handle for manual operation as standard, or spring catch for pole operation where required.

2.8.3 PERFORMANCE REQUIREMENTS:

2.8.3.1 *Physical Load Tests. Note: Samples submitted for Physical Load Test shall be of standard construction containing projected-out ventilator of manufacturer's largest standard size at least 4 x 8 feet.*

A.—Torsion Load Test on unglazed window with projected-out ventilator open to 45°, securely clamped and continuously supported around the outside perimeter, one free corner of the open ventilator securely held in the 45° position by blocking between the corner of the ventilator and the fixed portion of the window. A concentrated load of 30 pounds acting from the outside, perpendicular to the plane of the fixed portion and applied to the free rail of the ventilator at the point of locking handle attachment, shall not cause a deflection at

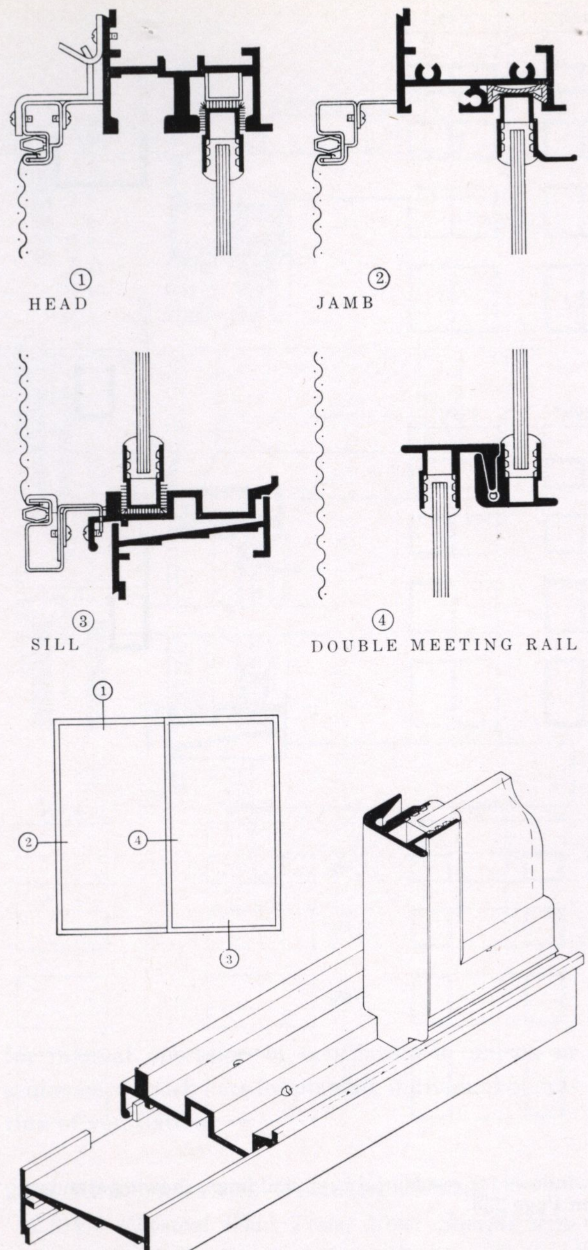


Figure 7-65: Horizontal sliding windows for residential type buildings, showing standard sizes and details. The double sill drains off both wind driven water and moisture from interior condensation. Concluded on Page 234.

the free corner opposite the blocked corner, measured perpendicular to plane of fixed portion, greater than 3½ inches.

B.—Uniform Load Test on complete unit. A glazed window with ventilator closed and locked

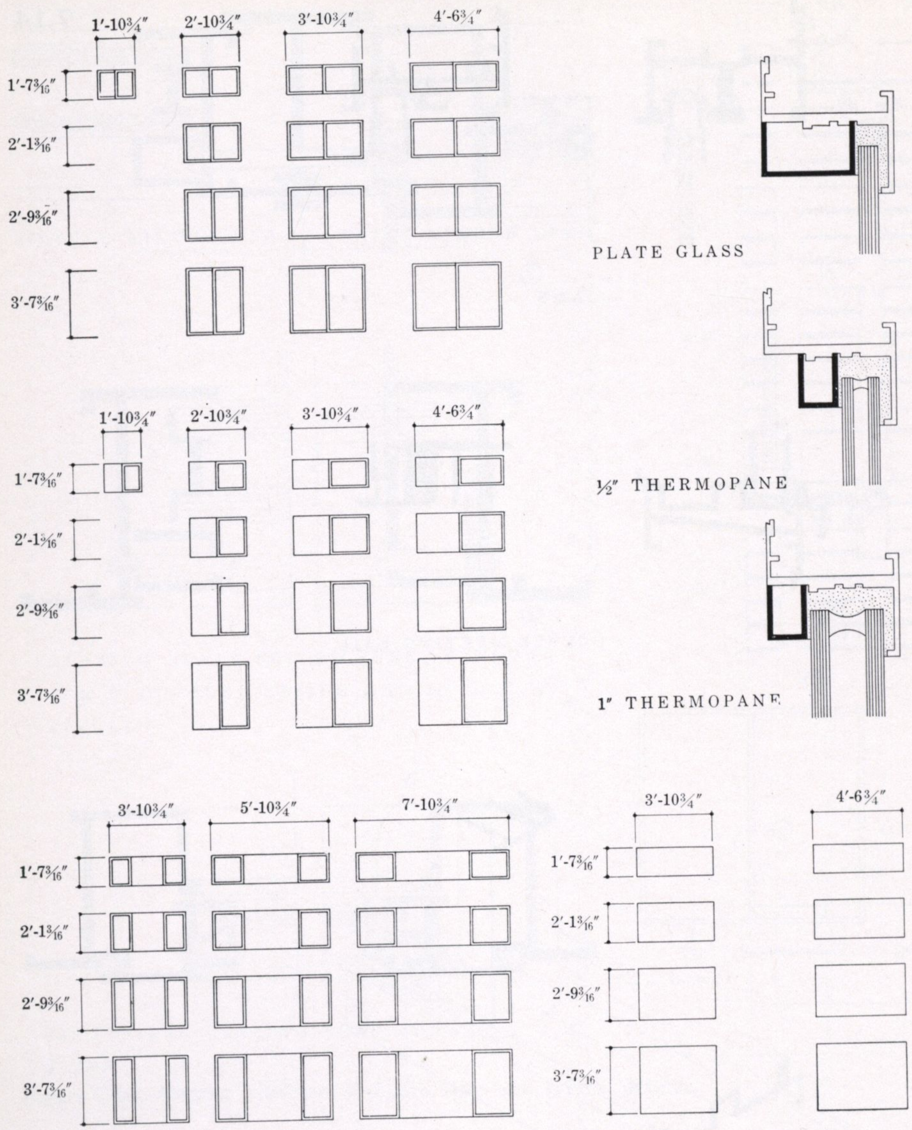


Figure 7-65: Horizontal sliding windows for residential type buildings, showing standard sizes and details. Concluded from Page 233.

shall be continuously supported around the outside perimeter and securely anchored. When subjected to an exterior uniform load of 15 pounds per square foot, applied perpendicular to and on the surface corresponding to the outside of the window, no member of a window unit or vertical or horizontal mullions shall deflect more than 1/175 of its span.

2.8.3.2 *Air Infiltration Test:* When tested in accordance with the procedure as outlined in Section 1 under Air Infiltration, the air infiltration shall not exceed one cubic foot per minute per foot of crack length with ventilator in closed position and locked (non-weatherstripped windows; ½ cubic foot for weatherstripped windows). The nominal size of the ventilators of the window tested shall be approximately 4 feet wide by 2 feet 8 inches high.

Manufacturers: The following companies manufacture a P-A2 type window which meets these specifications and are eligible to display the "Quality-Approved" Seal. Alcasco Products, Inc., 12640 Burt Road, Detroit, Mich. (*Series P-100 Intermediate Projected*). The Wm. Bayley Co., 1200 Warder St., Springfield 99, Ohio. Ceco Steel Products Corporation (*Sterling Aluminum Window Division*), 5601 West 26th St., Chicago 50, Ill. (*Series 525*). Cupples Products Corp., 2650 So. Hanley Road, Maplewood, St. Louis 17, Mo. (*Series 700, 800 and 900*). Fentron Industries, Inc., 2801 Market St., Seattle 7, Wash. (*Series 310-Projected*). Michael Flynn Mfg. Co., 700 East Godfrey Ave., Philadelphia 24, Pa. (*Lupton, Master Projected*). General Bronze Corp., Stewart Ave., Garden City, N. Y. (*Permatite, Series CPA-2 Projected*). Reynolds Metals Co., (*Window Division*), 2000 S. 9th St., Louisville, Ky. (*Series 500 and 600 Commercial Projected*). J. S. Thorn Co., 8501 Hegerman St., Philadelphia 36, Pa. (*Series A-6000 P*). Universal Window Co., 950 Parker St., Berkeley 10, Cal. (*Series S-300 and S-500*). Ware Laboratories, Inc., 3700 N.W. 25th St., Miami, Fla.

Specification A-A1: Awning Windows For Residential Type Buildings: *Section 1 in its entirety is a part of this specification.*

2.9.1 General: Awning windows are those windows consisting of a multiplicity of top-hinged ventilators arranged in a vertical series and operated by one or more control devices which swing the bottom edges of the ventilators outward. The hinges may be sliding or fixed. The ventilators may be operated simultaneously, in sequence or individually. The ventilators may close and weather on themselves or on independent meeting rails assembled as part of the window frame. There may or may not be fixed glass units between the ventilators.

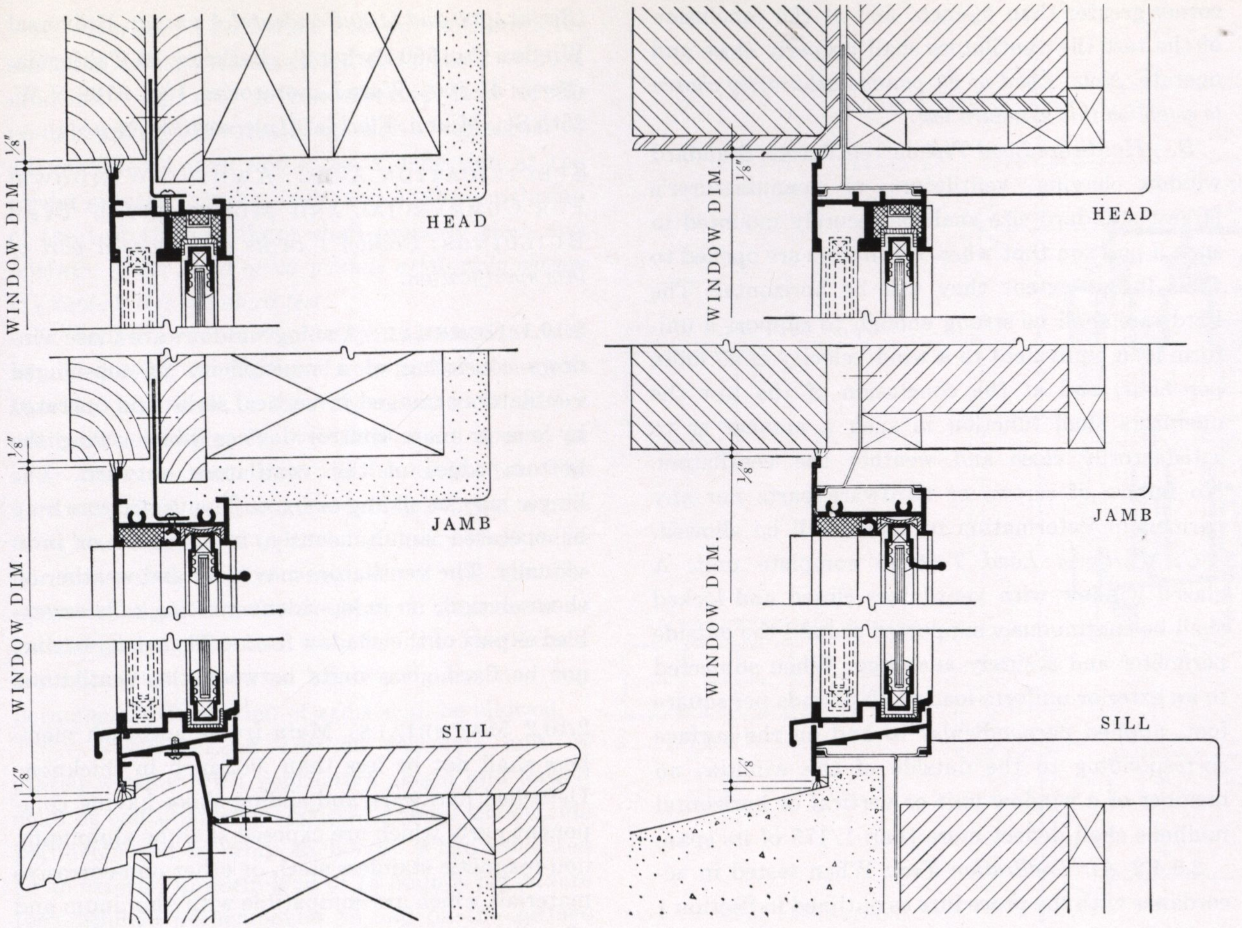


Figure 7-66: Examples of typical sliding window installations.

2.9.2 MATERIALS: Main frame and sash members shall not be less than .062-inch in thickness. Detached hardware and sliding shoes having component parts which are exposed shall be aluminum, non-magnetic stainless steel, or other non-corrosive materials which are compatible with aluminum and of sufficient strength to perform the functions for which they are used. Bronze hardware may be used provided that it have a heavy deposit of chrome plate and is properly insulated from direct contact with the aluminum.

2.9.3 HARDWARE: Satisfactory hardware shall be provided to control and securely lock the ventilators. Detached hardware shall consist of roto type operator for crank type operation or locking handle for manual operation of ventilators in unison or sequence, or push bars for manual, individual operation of ventilators.

2.9.4 PERFORMANCE REQUIREMENTS:

2.9.4.1 *Physical Load Tests. Note: Sample window submitted for Physical Load Tests shall be of standard construction of manufacturer's largest standard size containing maximum number of largest standard size ventilators* at least 3 feet by 5 feet 3 inches.

A.—Horizontal Deflection Test on ventilators installed in window frame, closed and locked, without muntins, unglazed. A concentrated load of 20 pounds acting individually on each lower corner of all ventilators shall not cause a deflection at the

corner greater than $3/8$-inch, and at the conclusion of the test the ventilators shall properly close and operate. *Note: Load of 20 pounds arbitrarily chosen to establish this standard test.*

B.—Hardware Load Test on ventilators. Standard window having ventilators of manufacturer's largest standard size shall be securely mounted in such a position that when ventilators are opened to their fullest extent they will be horizontal. The hardware shall be strong enough to support a uniform load equivalent to a wind velocity of 50 miles per hour, and at the conclusion of the test the operators shall function in such a manner as to satisfactorily close and weather the ventilators. No failure of screws or hardware parts nor any permanent deformation of arms shall be allowed.

C.—Uniform Load Test on complete unit. A glazed window with ventilators closed and locked shall be continuously supported around the outside perimeter and securely anchored. When subjected to an exterior uniform load of 10 pounds per square foot, applied perpendicular to and on the surface corresponding to the outside of the window, no member of a window unit or vertical or horizontal mullions shall deflect more than 1/175 of its span.

2.9.4.2 *Air Infiltration Test:* When tested in accordance with the procedure as outlined in Section 1 under AIR INFILTRATION, the air infiltration shall not exceed one cubic foot per minute per foot of crack length with ventilators in closed position and locked (non-weatherstripped; ½ cubic foot for weatherstripped windows). The window tested shall be of a nominal size of 3 feet wide x 4 feet high and shall be 100 percent ventilated, using manufacturer's standard ventilator arrangement.

Manufacturers: The following companies manufacture an A-A1 type window which meets these specifications and are eligible to display the "Quality-Approved" Seal. Fentron Industries, Inc., 2801 Market St., Seattle 7, Washington. (*Series 30-Awning*). Michael Flynn Mfg. Co., 700 Godfrey Ave., Philadelphia 24, Pennsylvania. (*Lupton Awning*). General Bronze Corp. (*Alwintite Division*), Stewart Ave., Garden City, New York. (*Alwintite, Series AWA-O*). Reynolds Metals Co. (*Window Division*), 2000 S. 9th St., Louisville, Kentucky. (*Series 4000 and 4100 Residental Awning*). Universal Window Co., 950 Parker St., Berkeley 10, California. (*Series M-200*). Ware Laboratories, Inc., 3700 N.W. 25th St., Miami, Florida. (*Intermediate Awning*).

SPECIFICATION A-A2: AWNING WINDOWS: FOR COMMERCIAL AND MONUMENTAL TYPE BUILDINGS: *Section 1 in its entirety is a part of this specification.*

2.10.1 GENERAL: Awning windows are those windows consisting of a multiplicity of top-hinged ventilators arranged in vertical series and operated by one or more control devices which swing the bottom edges of the ventilators outward. The hinges may be sliding or fixed. The ventilators may be operated simultaneously, in sequence or individually. The ventilators may close and weather on themselves or on independent meeting rails assembled as part of the window frame. There may or may not be fixed glass units between the ventilators.

2.10.2 MATERIALS: Main frame and sash members shall not be less than .062-inch in thickness. Detached hardware and sliding shoes having component parts which are exposed shall be aluminum, non-magnetic stainless steel, or other non-corrosive materials which are compatible with aluminum and of sufficient strength to perform the functions for which they are used. Bronze hardware may be used provided that it has a heavy deposit of chrome plate and is properly insulated from direct contact with the aluminum.

2.10.3 HARDWARE: Satisfactory hardware shall be provided to control and securely lock the ventilators. Detached hardware shall consist of roto type operator for crank type operation or locking handle for manual operation of ventilators in unison or sequence, or push bars for manual, individual operation of ventilators.

2.10.4 PERFORMANCE REQUIREMENTS:

2.10.4.1 *Physical Load Tests. Note: Sample window submitted for Physical Load Tests shall be of standard construction of manufacturer's largest standard size containing maximum number of largest standard size ventilators at least 4 x 8 feet.*

A.—Horizontal Deflection Test on ventilators installed in window frame, closed and locked, without muntins, unglazed. A concentrated load of 20 pounds acting individually on each lower corner of all ventilators shall not cause a deflection at the corner greater than $^{5}/_{16}$-inch, and at the conclusion of the test the ventilator shall properly close and operate. *Note: Load of 20 pounds arbitrarily chosen to establish this standard test.*

B.—Hardware Load Test on ventilators. Standard window having ventilators of manufacturer's largest standard size shall be securely mounted in such a position that when the ventilators are opened to their fullest extent they will be horizontal. The hardware shall be strong enough to support a uniform load equivalent to a wind velocity of 50 miles per hour, and at the conclusion of the test the operators shall function in such a manner as to satisfactorily close and weather the ventilators. No failure of screws or hardware parts nor any permanent deformation of arms shall be allowed.

C.—Uniform Load Test on complete unit. A glazed window with ventilators closed and locked shall be continuously supported around the outside perimeter and securely anchored. When subjected to an exterior uniform load of 15 pounds per square foot, applied perpendicular to and on the surface corresponding to the outside of the window, no member of a window unit or vertical or horizontal mullions shall deflect more than 1/175 of its span. *Note: Due to the great variation of design and arrangements of ventilating units required by windows of this type and class, this uniform load test cannot be performed except on a standard unit such as that specified above. In order to ensure uniformity of strength of all members required in any type of multiple unit opening, the manufacturer shall guarantee the use of a design for mullions, transom bars and other connecting members that will not permit a deflection greater than 1/175 of the span of any member under conditions simulating the load test described immediately above.*

2.10.4.2 *Air Infiltration Test:*

A.—Windows With Weatherstripping. When tested in accordance with the procedure as outlined in Section 1 under AIR INFILTRATION, the air in-

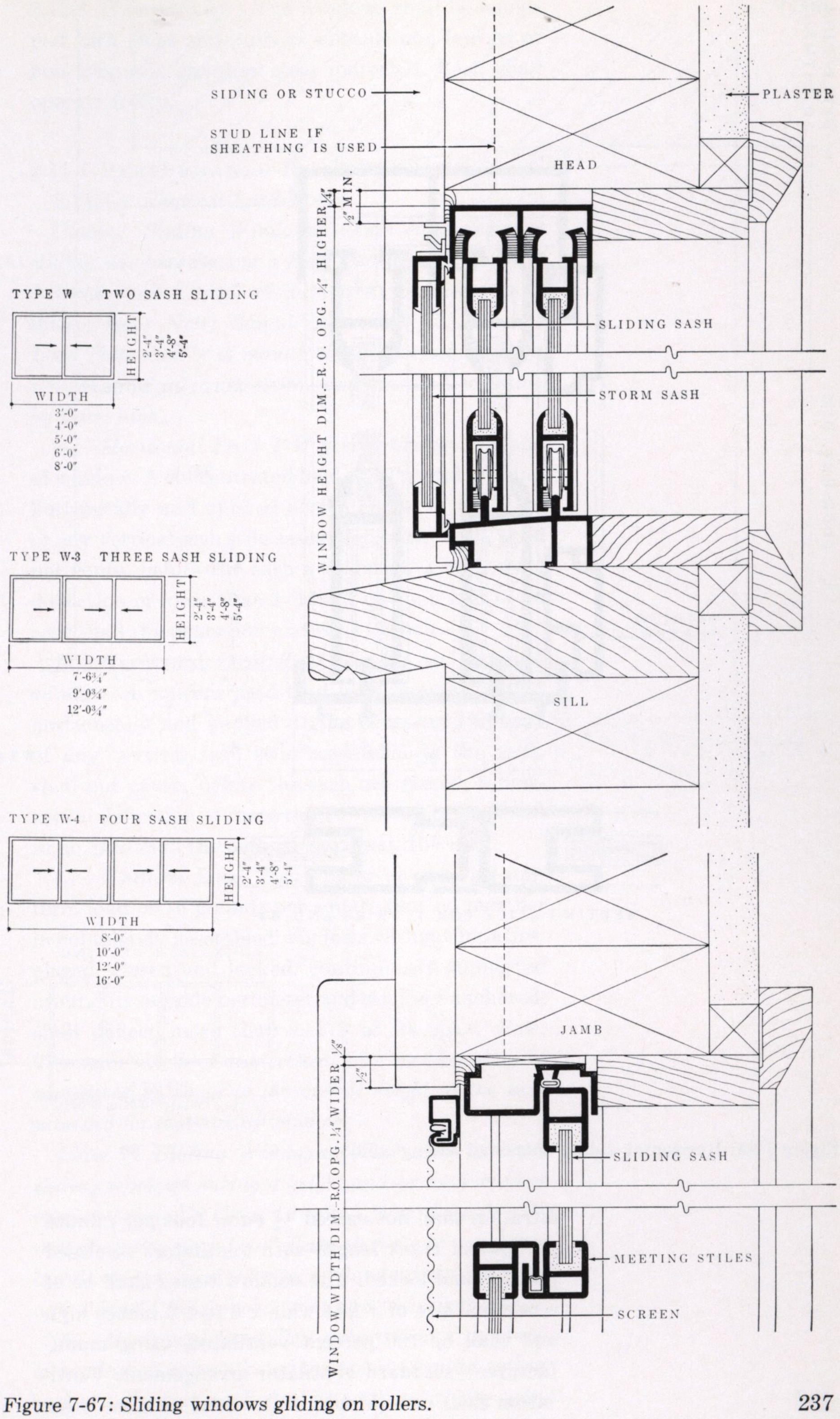


Figure 7-67: Sliding windows gliding on rollers.

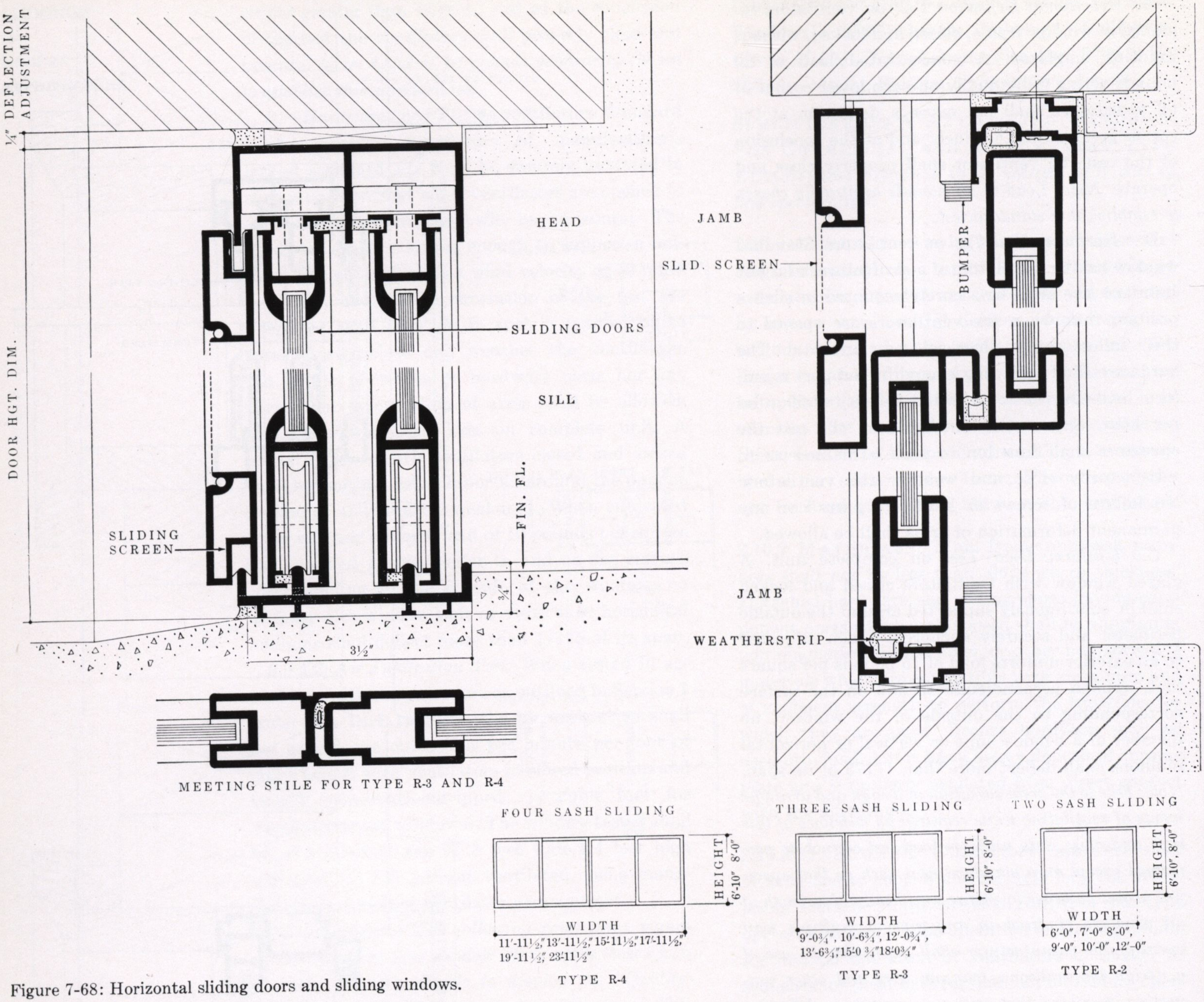


Figure 7-68: Horizontal sliding doors and sliding windows.

filtration shall not exceed ½ cubic foot per minute per foot of crack length with ventilators in closed position and locked. The window tested shall be of a nominal size of 4 feet wide x 5 feet 6 inches high and shall be 100 percent ventilated, using manufacturer's standard ventilator arrangement. Ventilators shall be equipped with metal or some other approved type of weatherstripping.

B.—Windows Without Weatherstripping. Where windows are specified to be of a design with two-point or three-point metal-to-metal contact without the use of auxiliary weatherstripping the air infiltration, when tested in accordance with the procedure as outlined in Section 1 under Air In-

FILTRATION, shall not exceed one cubic foot per minute per foot of crack length with ventilators in closed position and locked. The window tested shall be of a nominal size of 4 feet wide x 5 feet 6 inches high and shall be 100 percent ventilated, using the manufacturer's standard ventilator arrangement.

Manufacturers: The following companies manufacture an A-A2 type window which meets these specifications and are eligible to display the "Quality-Approved" Seal. Cupples Products Corp., 2650 So. Hanley Road, Maplewood, St. Louis 17, Mo. Fentron Industries, Inc., 2801 Market St., Seattle 7, Wash. (*Series 310-Awning*). Michael Flynn Mfg. Co., 700 Godfrey Ave., Philadelphia 24, Pa. (*Lupton Awning*). Reynolds Metals Co. (*Window Division*), 2000 S. 9th St., Louisville, Ky. (*Series 4000 and 4100 Commercial Awning*). J. S. Thorn Co., 8501 Hegerman St., Philadelphia 36, Pa. (*Series A-1000*). Universal Window Co., 950 Parker St., Berkeley 10, Cal. (*Series M-200*). Ware Laboratories, Inc., 3700 N.W. 25th St., Miami, Fla.

SPECIFICATION DS-A1: DOUBLE-SLIDING (AND SINGLE-SLIDING) WINDOWS FOR RESIDENTIAL TYPE BUILDINGS: *Section 1 in its entirety is a part of this specification.*

2.11.1 MATERIALS: Main frame and sash members shall not be less than .062-inch in thickness.

2.11.2 CONSTRUCTION: 2.11.2.1 Frames and/or sash units shall be completely assembled at the plant of the manufacturer or by duly authorized representatives.

2.11.2.2 Frames shall be constructed to permit horizontal movement of sash. Meeting stiles shall contact tightly with each other or with weatherstrips. Sash shall not be removable from the outside when locked.

2.11.2.3 Provision shall be made in sill for exterior drainage of water.

2.11.2.4 Where Single-Slide windows or Multiple-Slide windows with fixed lights are specified, they shall meet all of the provisions applying to the Double-Slide windows as herein specified.

2.11.3 HARDWARE: The windows shall be equipped with locks and pulls of suitable non-ferrous or non-magnetic stainless steel materials. Sash shall operate freely.

2.11.4 PERFORMANCE REQUIREMENTS:

2.11.4.1 *Physical Load Tests:*

Class 1 Sliding Windows: (This class includes sliding windows having a height not exceeding 2 feet 6 inches and a total window area not exceeding 9 square feet.) Note: Sample submitted for Physical Load Tests shall be of manufacturer's largest standard size, of standard construction, and at least 4 feet wide by 2 feet high.

A.—Horizontal Load Test perpendicular to plane of window. A concentrated load of 10 pounds, acting horizontally and applied at the center of the span of any vertical sash stile assembled in the sash, shall not cause, before the sash are glazed, a horizontal deflection of more than 1/165 of its span and in no case shall the deflection exceed .145-inch.

B.—Horizontal Load Test parallel to plane of window. A concentrated load of 10 pounds, acting horizontally and applied at the center of the span of any vertical sash stile assembled in the sash, shall not cause, before the sash are glazed, a horizontal deflection of more than 1/160 of its span and in no case shall the deflection exceed .150-inch.

C.—Uniform Load Test. Under an exterior uniform load of 10 pounds per square foot no member in completely assembled windows without muntins, glazed, closed and locked, continuously supported around its outside perimeter and securely anchored, shall deflect more than 1/175 of its span. *Note: The span length of any vertical sash member shall be considered as equal to the overall height of the sash provided for that size of window.*

Class II Sliding Windows: (This class includes sliding windows having a height and/or total window area exceeding the Class I limits.) Note: Sample submitted of Physical Load Tests shall be of manufacturer's largest standard size, of standard construction, and at least 4 feet 6 inches wide by 3 feet 6 inches high.

A.—Horizontal Load Test perpendicular to plane of window. A concentrated load of 10 pounds, acting horizontally and applied at the center of the span

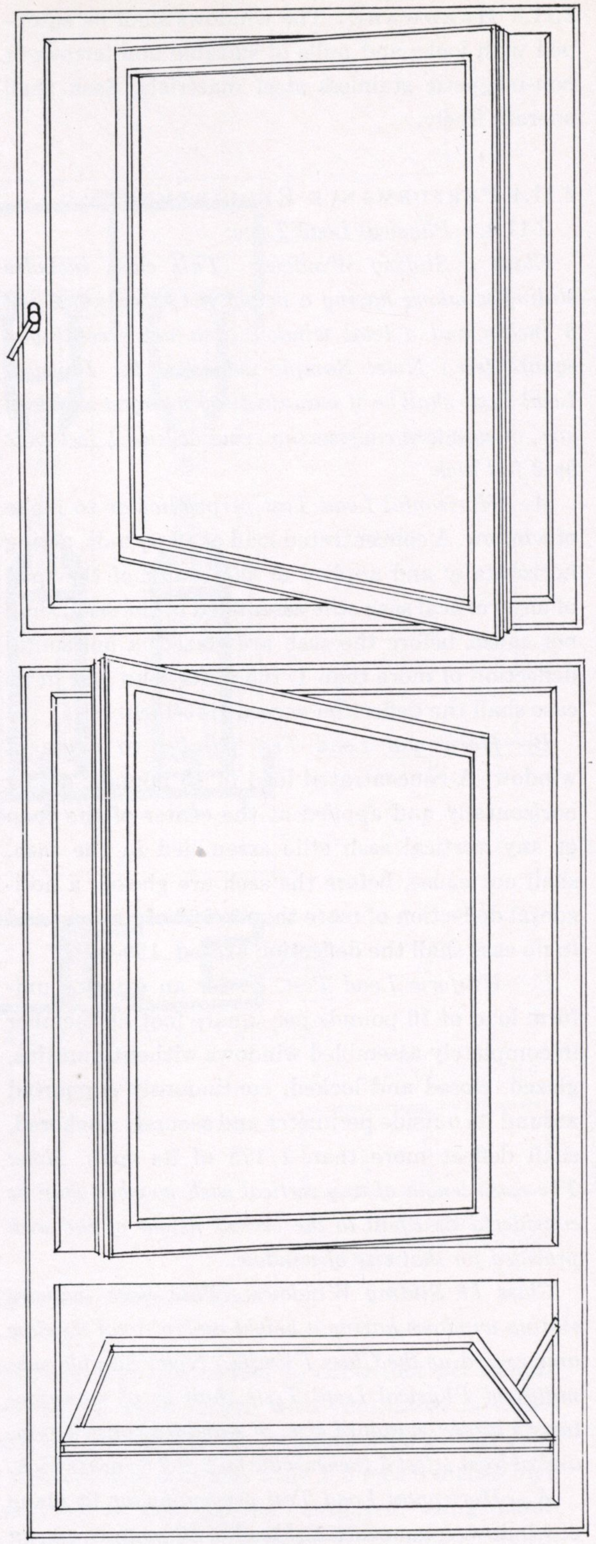


Figure 7-69: Vertically pivoted windows.

of any vertical sash stile assembled in the sash, shall not cause, before the sash are glazed, a horizontal deflection of more than 1/175 of its span and in no case shall the deflection exceed .240-inch.

B.—Horizontal Load Test parallel to plane of window. A concentrated load of 10 pounds, acting horizontally and applied at the center of the span of any vertical sash stile assembled in the sash, shall not cause, before the sash are glazed, a horizontal deflection of more than 1/175 of its span and in no case shall the deflection exceed .240-inch.

C.—Uniform Load Test. Under an exterior uniform load of 10 pounds per square foot no member in completely assembled window without muntins, glazed, closed and locked, continuously supported around its outside perimeter and securely anchored, shall deflect more than 1/175 of its span. *Note: The span length of any vertical sash member shall be considered as equal to the overall height of the sash provided for that size of window.*

2.11.4.2 *Air Infiltration Test.* When tested in accordance with the procedure as outlined in Section 1 under AIR INFILTRATION, the air infiltration shall not exceed ¾ cubic foot per minute per foot of crack length with sash in closed position and locked. The sash shall have been adjusted to operate in either direction with a force not exceeding 10 pounds after the sash is in motion. The nominal size of the window tested shall be 4 feet wide by 2 feet high or have a frame and integral sash perimeter equal thereto for Class I Sliding Windows and 4 feet wide by 3 feet high or have a frame and integral sash perimeter equal thereto for Class II Sliding Windows.

2.11.4.3 *Water Resistance Test.* When subjected for a period of 15 minutes to dynamic testing conditions as established by the Aluminum Window Manufacturers Association, consisting of a flow of water downward (through a horizontal area defined by rotating the window unit 90° about an axis 6 inches above the head of the window unit) at a rate equivalent to a rainfall of 2 inches per hour introduced into an airstream of 45 miles per hour velocity directed perpendicular to the exterior face of the window, no water shall overflow the sill on the interior face of the window over an area encompassing the size of the window tested. The

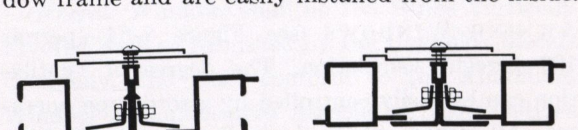
above pressure differential shall be maintained throughout the test. The sash shall be equipped with manufacturer's standard insect screen and set true, plumb, level and square. The sash shall have been adjusted to operate in either direction, in any position, with a force not exceeding 10 pounds. The nominal size of the window tested shall be identical to that specified under paragraph 2.11.4.2 of the Air Infiltration Test.

Manufacturers: The following companies manufacture a DS-A1 type window which meets these specifications and are eligible to display the "Quality-Approved" Seal. Alcasco Products, Inc., 12640 Burt Road, Detroit 23, Mich. (*Series S-100 Horizontal Sliding*). Cupples Products Corp., 2650 So. Hanley Road, Maplewood, St. Louis 17, Mo. Ceco Steel Products Corp., (*Sterling Aluminum Window Div.*), 5601 West 26 St., Chicago 50, Ill. (*Series 700*). General Bronze Corporation (*Alwintite Division*), Stewart Ave., Garden City, N. Y. (*Series D, M, VF*). Luria Building Products, Box 27, Bristol, Pa. (*Series 40, 60, 61, 100 and 101*). Metal Arts Mfg. Co., Inc., Harwell & Oakcliff Rd., Atlanta, Ga. Reynolds Metals Co. (*Window Division*), 2000 S. 9th St., Louisville, Ky. (*Series 5000 Traverse Window*). J. S. Thorn Co., 8501 Hegerman St. Philadelphia 36, Pa. (*Series A-300*).

DOUBLE-HUNG WINDOWS: Balancing mechanism makes easy operation possible and holds the sash in any open position.

Double-Hung Windows for Residential Type Buildings are available without muntins and also in various muntin arrangements (see Figure 7-51).

Aluminum screens and storm sash are available in standard sizes. Both attach flush to outside of window frame and are easily installed from the inside.

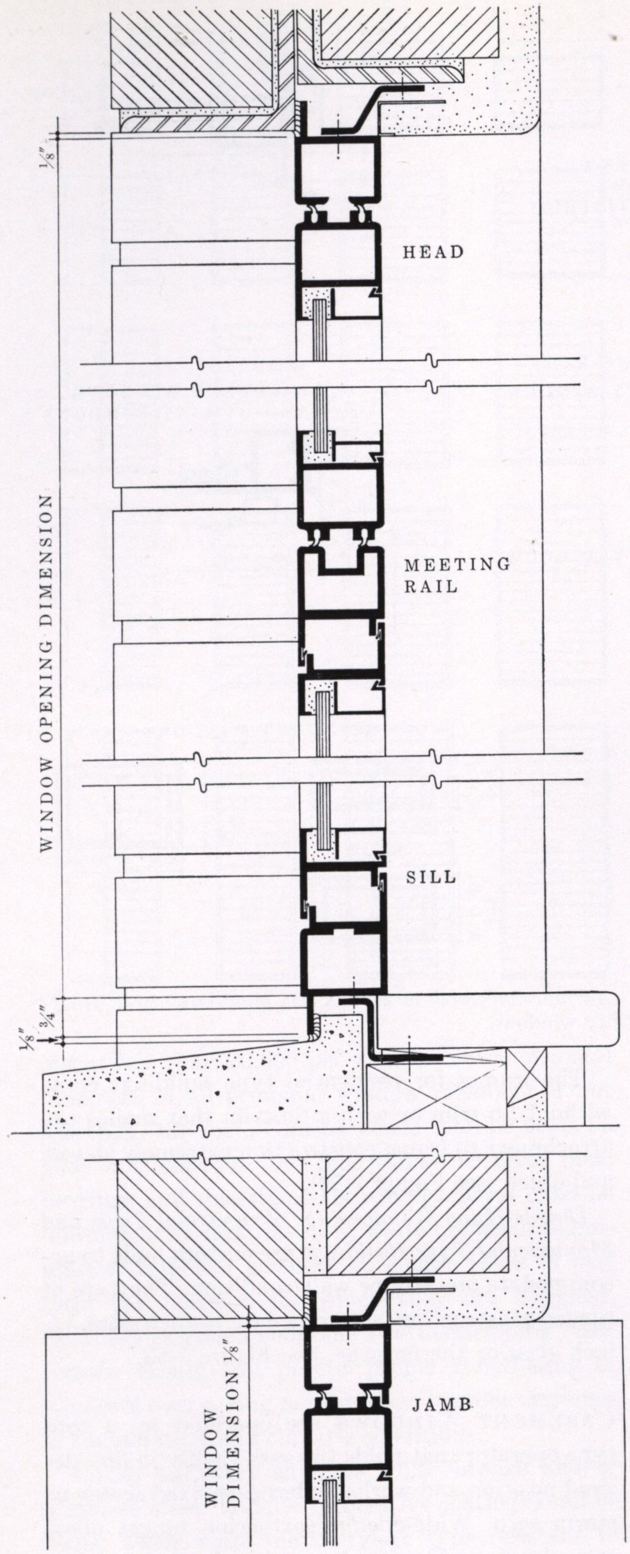


FOR WINDOWS 5' TO 7' HIGH

FOR WINDOWS UP TO 5' HIGH

MULLIONS

Figure 7-70: Vertically pivoted window as manufactured by Reynolds Metals. The frame sections may be adjusted to meet the requirements of the wall construction. The design can be modified within the limitations of a maximum size of 5 feet x 7 feet.



PIVOTED SASH

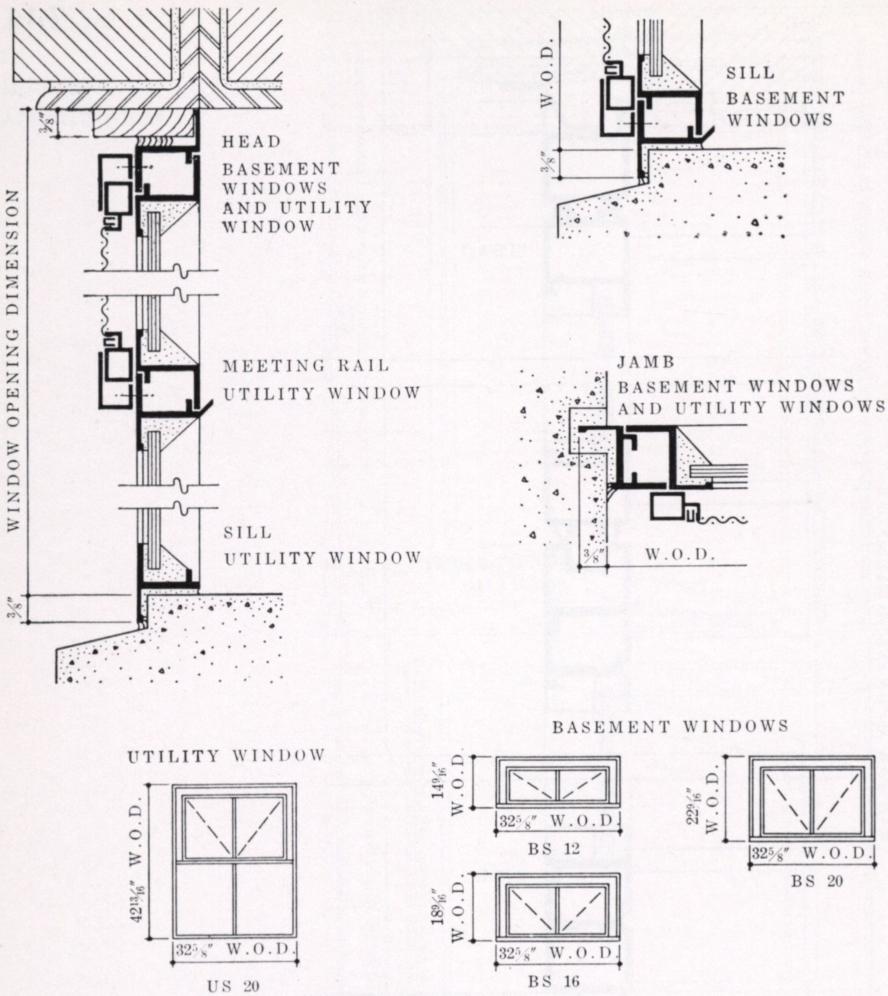


Figure 7-71: Basement and utility windows.

The frames for residential type buildings come without fin trim or with a fin trim that makes the attachment to frame construction extremely simple and quick (see Figure 7-52).

Double-Hung Windows for Commercial Type and Monumental Type Buildings are custom built to accommodate any size or wall condition. They are of rugged construction; accommodate $\frac{1}{8}$-inch glass, $\frac{1}{4}$-inch glass or thermopane. See Figure 7-53.

Casement Windows are operated by a roto type operator that holds the sash rigidly in any desired position and works underneath fixed screen or storm sash. Wide-opening extension hinges allow easy cleaning of both sides of glass from the inside. Standard size aluminum screens require no fitting or marking for storage and are installed from inside by simple clips. Casement windows are available for residential type buildings and for commercial and monumental type buildings.

Figures 7-54 to and including 7-61 show various types of casement windows for residential type buildings.

Figure 7-62 shows standard casement windows for commercial and monumental type buildings. The windows illustrated are completely flush both inside and out. Frames are designed so that there are no projections or offsets to interrupt the clean, modern lines. Note also that all glass is in the same plane.

Serrated webs and glazing compound retaining lips make glazing easier and more secure. All glazing is done from the outside with the use of either glazing compound or mechanical glazing beads. Complete weatherstripping with neoprene extrusions is an optional feature and can mean considerable savings in heating and air-conditioning costs.

Projected Windows: Standard sizes for residential, commercial and monumental type buildings are shown in Figure 7-63. Projected windows for commercial and monumental type buildings are available in a great variety of sizes and sash combinations of projecting and hopper sash that provide flexible and efficient ventilation. Windows are available with vertical and/or horizontal muntins. Picture windows are also available. In addition to standard sizes, these windows are manufactured to special sizes and combinations of fixed and operating sash, within the exceptionally wide limits of the material.

Awning Windows (see Figure 7-64) permit 100 percent ventilation. The degree of ventilation can be easily controlled by a roto type operator. All vents are held rigidly in any position without interference with screens, storm sash, blinds or curtains. The open sash sheds water, thus providing partial weather protection. The closing surfaces are protected against air and water infiltration by special vinyl weatherstripping. Stand-

ard size aluminum screens require no fitting. Ventilated or fixed storm sash are also available. Both fit flush inside frame. Awning windows can be combined with fixed units, single or double glazed.

HORIZONTAL SLIDING WINDOWS: This type window eliminates any projection of the sash to the outside or inside. There is no interference with screens, blinds, shades or curtaining. The appearance is architecturally very pleasing. They are simple to operate and, if properly designed, extremely weathertight.

Windows up to a limited height have vents sliding on wool pile or on a weatherstrip made of other material such as zinc. Representative of this type are the typical windows illustrated in Figures 7-65 through 7-68.

VERTICALLY PIVOTED WINDOWS: This type is especially suitable for multi-story buildings. It is designed for *ease of cleaning* from the interior of the building with a safety feature built into a key lock that opens easily but permits removal of the key only if the window is fully closed. These windows ensure a *minimum of air infiltration*, which is so important in the design of air-conditioned buildings. This is accomplished by a double gasket, friction seal weatherstripping. Vertically pivoted windows are manufactured to the architect's specifications. (Figures 7-69 and 7-70).

VERTICALLY PIVOTED WINDOWS—SPECIFICATIONS: No specifications have been issued for this type of window by the Aluminum Window Manufacturers Association. The following specification is suggested by Reynolds Metals Company:

General: Windows shall be 100 Series Vertically Pivoted Sash as furnished by the Reynolds Metals Company, and shall conform to the Aluminum Window Manufacturers Association specifications as outlined in Section 1. Windows shall be furnished with or without hopper vents to the sizes and types as shown on the drawings.

Material: Frame and ventilator sections shall be especially designed aluminum extruded shapes of 6063-T5 alloy having an ultimate tensile strength of not less than 22,000 psi with a minimum metal thickness in all principal window members of not less than .125-inch. Glazing beads shall be 6063-T5 alloy not less than .062-inch thick. All pivot pins, bearings and miscellaneous window parts shall be non-magnetic stainless steel, white bronze or aluminum of sufficient strength to enable them to perform the function for which they are designed. Specially extruded neoprene weatherstripping must remain elastic and permit proper functioning of windows over a long period of time under extremes of temperature and climatic conditions.

Finish hardware shall be white bronze and/or stainless steel. Lacquer protective coatings shall be clear, water-white methacrylate type resistant to the action of lime mortar.

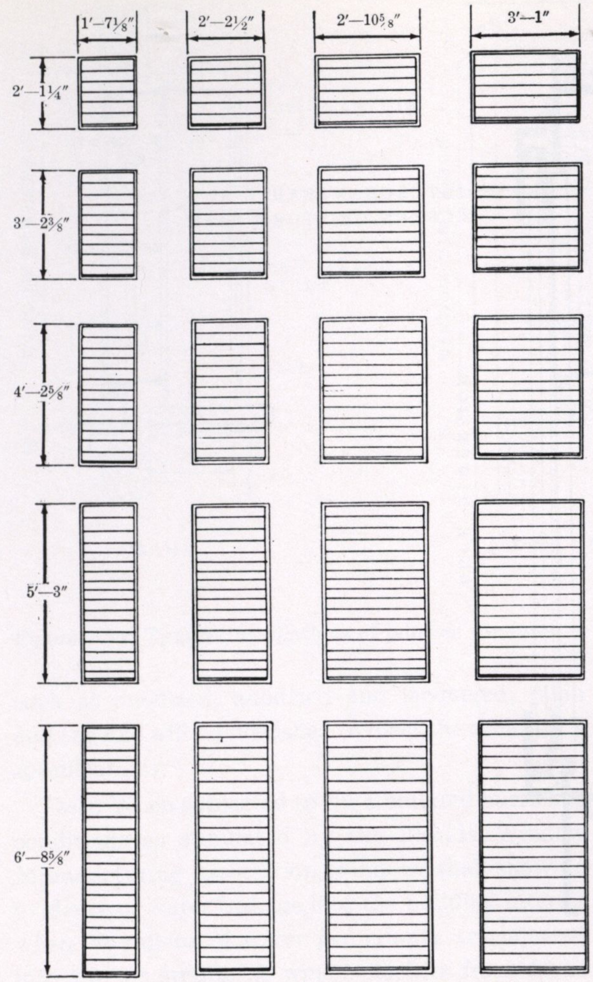


Figure 7-72: Available stock sizes of jalousie windows.

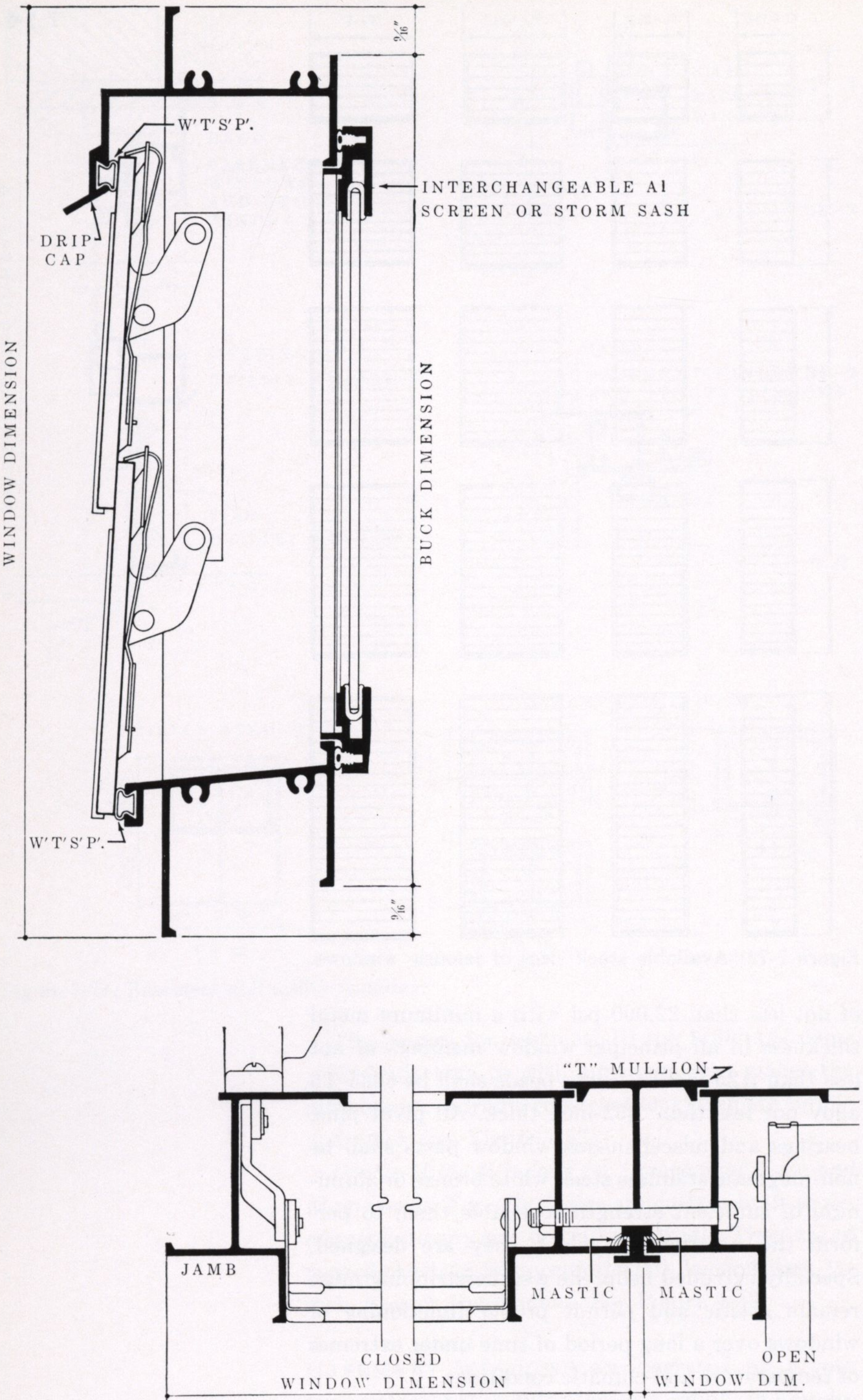


Figure 7-73: Typical details of jalousie windows.

CONSTRUCTION:

Frames: Corners of frame sections shall be securely welded from the inside around the entire perimeter of the joint. Joint design and welding shall be such as to permit anodizing of frame without discoloration or deformation of the exposed faces. Frames shall be of special design which permits collection and drainage of any water passing exterior weathering seal down through frame and out weep holes provided in the sill section. Frame sections, at jambs only, shall have integrally extruded flanges which accurately position the pivoted sash in the washing position as well as the fully closed position. The flange design shall be such as to provide an additional weathering contact with the pivoted vent along each jamb; to ensure accurate alignment between frame and pivoted sash of double Neoprene weathering seals and locking devices; and to ensure that the original position of the exterior and interior faces of the pivoted sash will remain fixed.

Pivoted Sash: Sash members shall be fastened at the corners by means of concealed die-cast aluminum corner inserts, accurately fitted into the hollow portion of the sash frame and securely fastened by means of concealed non-magnetic stainless steel screws. Before assembly, these inserts shall be coated with an approved type sealing compound. Design of pivoted sash shall be such as to permit the sash to revolve counter-clockwise approximately 180°, in which position the sash may be securely locked to permit washing of exterior surfaces from the interior of the building. Design of sash also shall be such as to permit rapid removal of entire pivoted portion and easy replacement with a spare vent.

Weatherstripping: Two parallel extruded neoprene weathering strips of special design and with vulcanized corners shall be provided to effect a positive seal between the pivoted sash and the window frame. These strips shall be securely anchored in special slots in the sash, shall contact the window frame firmly around its perimeter at two mating positions, and shall be of such design and type as to afford the degree weathertightness specified in the performance requirements listed under "Tests"

below. Design of weatherstripping shall be such as to permit replacement.

Hardware: Locking devices shall consist of two concealed cam type locks of aluminum or non-magnetic stainless steel, one mounted in each jamb of the window frame. (Where pivoted sash is over 60 inches in height, four such locks shall be provided.) Operation of the locks shall be by means of a special key of chrome-plated steel which can be removed from the locks only when the pivoted sash has been returned to the fully closed position and is positively locked. Locking keys shall be provided in the quantity specified (specify quantity). All hardware parts shall be so designed as to permit replacement.

Hopper Vents: Where windows are scheduled and specified to be provided with hopper vents, special inward-operating vents shall be furnished to the sizes shown on the drawings. Vents shall be designed for inside glazing and provided with operating arms and adjustable friction shoes, which will effectively hold the vent in any open position to a maximum of 45°. Design of vent sections shall be such as to provide flush interior and exterior surfaces conforming to the lines of the window frame and pivoted sash and to provide double extruded neoprene weathering contacts around the perimeter of the vent, which afford the same general weathertightness as that of the pivoted sash. Design of the hopper vent shall also permit entrapment of any water leakage past lower contact and drainage through weep holes in frame as described above. Cam action locking handles and strikes shall be white bronze; shoe housings shall be die-cast aluminum, and shall have nylon friction shoes.

Glazing: Glazing shall be as specified under the "Glass and Glazing" Section of the general specifications and shall be furnished and installed by the contractor for that portion of the work. Glazing shall be effected by means of special aluminum glazing beads applied on the interior and furnished as a part of the window to conform to the glass thickness specified.

Finish: All windows shall be furnished with a chemically cleaned, etched, anodized (30 minutes), and spray-lacquered finish. Other types of finishes

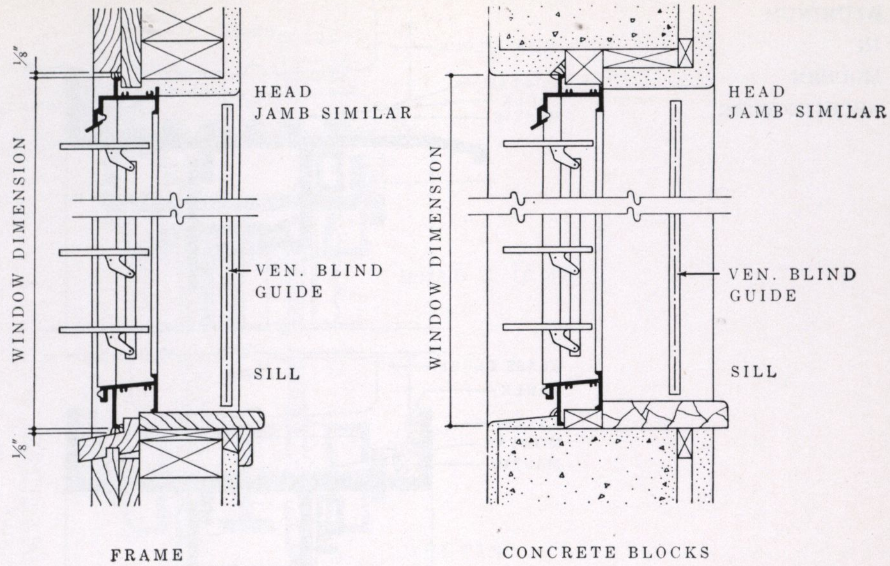


Figure 7-74: Typical installations of jalousie windows.

such as anodized, anodized and lacquered, plain and the like will be furnished to meet the architect's specifications.

Tests: When subjected to the simulated hurricane conditions as stipulated by the Florida Window Manufacturing Association, windows shall show no evidence of water leakage into the building interior when 20 gallons of water per minute are injected into the air stream at wind velocities from 50 to 110 mph for a duration of not less than 15 minutes. Total air infiltration through the window when subjected to the Florida Window Manufacturers' tests shall not be greater than .10 cfm at an average wind velocity of 50 mph.

Upon request, manufacturer will provide evidence showing compliance with these specifications.

BASEMENT AND UTILITY WINDOWS: Frames have serrated edges that grip masonry. Two guide arms hold vent rigid in all open positions. The vent is removable for easy cleaning. The vents have double contact with window frame and there are no overlapping edges—vent and frame fit flush inside and out. Figure 7-71 shows typical units of this type.

No standard specifications for this type have

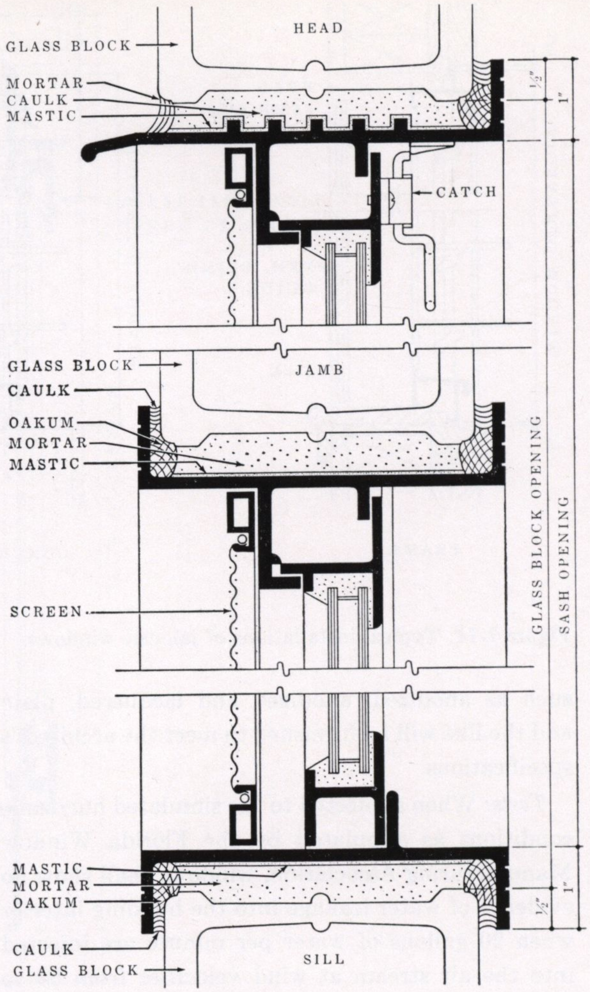


Figure 7-75: Ventilating sash for glass block walls.

been issued by the Aluminum Window Manufacturers Association. The following specification is suggested by Reynolds Metals Company:

General: Windows shall be Aluminum Basement and/or Utility type as manufactured by Reynolds Metals Company and designed for use in basements, garages, areaways, and the like (or with design and/or engineering changes which will provide the user with equal or superior operation, appearance and service). Sizes and types shall be as shown on the general plans.

Material: Sections shall be specially designed aluminum extruded shapes of 6063-T5 alloy having an ultimate tensile strength of not less than 22,000 psi, with a minimum thickness of .062-inch. Frame and ventilator sections shall be Z-Sections 1-inch in depth with offset weathering.

Construction: All corners shall be of the mortise and tenon type, securely riveted to provide sturdy tight corners. Vent arms shall be securely riveted to ventilator and slide in the frame tracks which shall be an integral part of the frame jamb extrusions. Frame members under the ventilator shall contain two weep holes to allow for water run-off. Vent shall open in at the top and pivot on the sill to a 45 degree angle. They shall further open to 90 degrees at any location on the frame from center of window frame to top. Vents shall also be designed for complete removal, if necessary, for cleaning of glass or to permit use of a clear opening for passage of materials to and from the basement. Sections shall provide continuous double contact between frame and ventilator members. Sections shall be designed so as to provide a flush surface on both the interior and exterior. In no case shall the ventilator overlap the outside or inside face of frame. All window sections shall be provided with serrated edges to ensure the adherence of either glazing compound or grouting material.

Hardware: Each window shall be provided with a cam type catch of aluminum riveted to the head of the ventilator which will pivot about a riveted pin to close and lock the window securely. Catch shall come attached to window.

All windows shall have a "Satinized" finish and a protective coating of a lime-resistant, water-white, methacrylate type lacquer, dip applied after chemical cleaning.

Erection: All windows shall be set by others level, plumb and square without springing, forcing or distortion, in accordance with the manufacturer's standard recommendations. When possible, windows shall be installed in the closed and locked position to insure proper ventilator alignment. Mastic provided by the window erector shall be used in sufficient quantity to provide a weathertight seal between windows and surrounding construction. All such joints must be thoroughly caulked. In no case use incompatible materials with aluminum. Where unprotected aluminum comes into contact with lime-content masonry, the surfaces shall be

coated by others with an approved type lacquer or bitumastic paint.

Glazing: All windows are factory adjusted; but prior to glazing, window shall be inspected to ensure that ventilators correctly seat and weather as per manufacturer's recommendations. If found incorrect, windows should be adjusted prior to the application of glass and compound. (This work is not done by Reynolds Metals Company.) All windows shall be putty glazed from the inside with an approved type aluminum window glazing compound, or bead glazed (beads furnished by Reynolds Metals Company at extra cost) on the inside as per manufacturer's recommendations. When using compound, glass shall be carefully bed-puttied and face-puttied in a neat manner, being secured with spring-type clips provided by the glazing contractor (not Reynolds Metals Company).

Screens and Storm Sash: Screens of the flat, fixed type shall be easily applied to, and removed from, all openings from the outside. Screen frames shall be tubular aluminum sections .75-inch in thickness and .438-inch in depth, securely joined at corners by force-fit inserts with a minimum thickness of .091-inch. Screen cloth shall be aluminum of an 18-14 mesh. Screens shall be furnished by the manufacturer (at extra cost).

Storm sash panels of a flat, fixed type shall be easily applied to, and removed from, the outside and shall cover entire window area. Glass shall be bedded in a neoprene or vinyl-type extrusion, which shall extend around the storm sash frame and provide a complete coverage between storm sash and window frame. Storm sash shall be furnished by the manufacturer (at extra cost).

Glass Louvered (Jalousie) Windows: This type of window provides maximum ventilation. The louvers are controlled by a roto type operator and lock in any position. The frames are designed for interchangeable inside screen and storm windows. The louvers are made of ¼-inch polished clear plate glass or obscure glass where privacy is required. See Figures 7-72 through 7-74.

Windows for Special Applications: In addition to the standard types of windows there are special products answering specialized needs. One

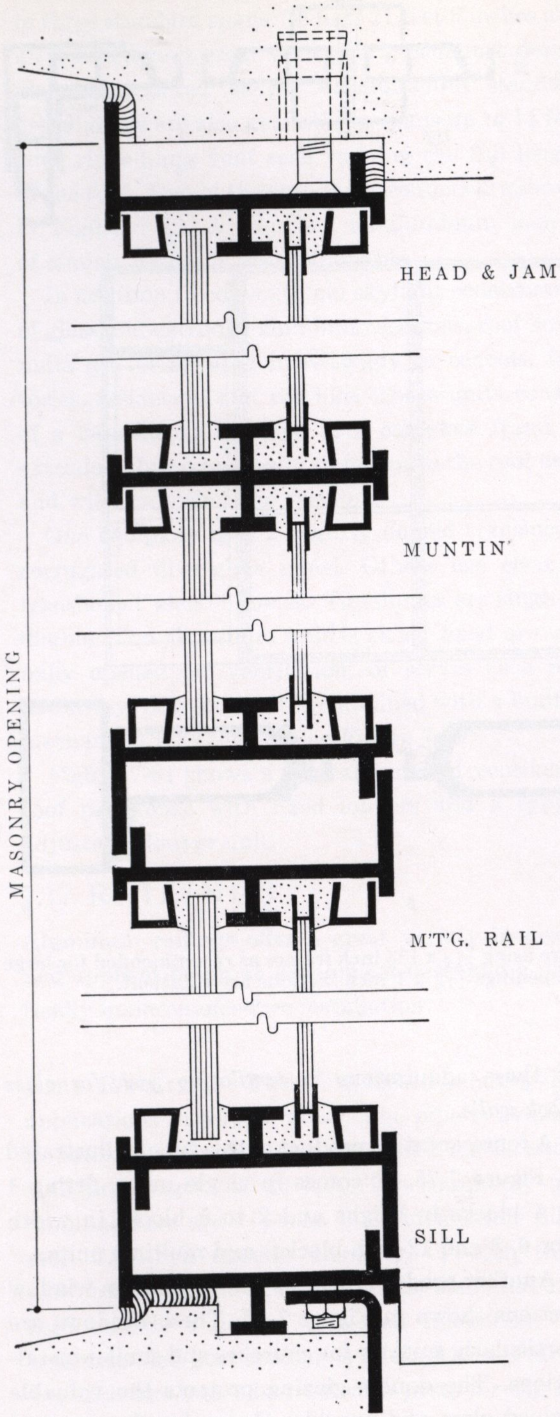


Figure 7-76: Twin-beam aluminum window.

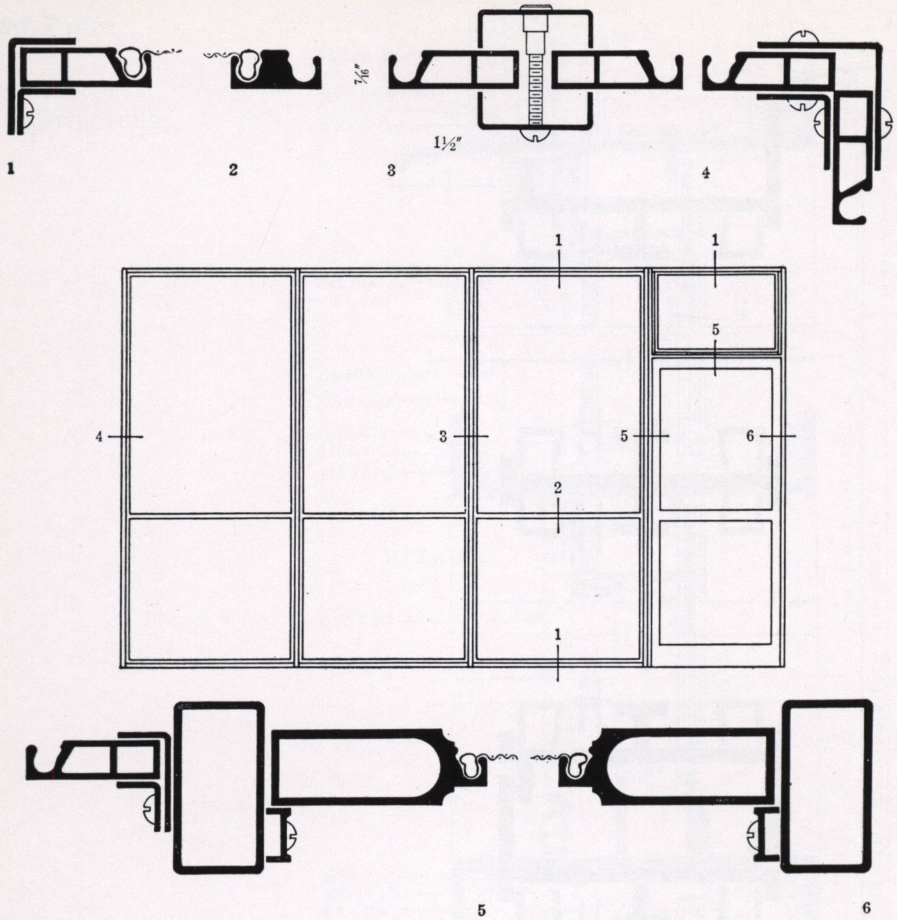


Figure 7-77: Screen porch enclosure using 7/16 x 1½ inch frames as recommended for large brace-free openings. For smaller openings 7/16 x 1 inch sections are sufficient.

of these adaptations is *ventilating sash for glass block walls.*

A representative product of this type is illustrated in Figure 7-75. It comes in single units, fitting 1 to 4 blocks in height and 2 to 5 blocks in width (for 6, 8 and 12-inch blocks) and multiple units.

Another product is the special aluminum window sections shown in Figure 7-76. These windows are particularly suitable for churches and similar installations. The double glazing protects the valuable stained glass and provides thermal and acoustical insulation. The aluminum sections can be formed readily to fit arched or circular windows.

Other examples of aluminum windows that can be custom built to fit special requirements and designs are illustrated in this book in Section 7.25 devoted to curtain walls.

STORM WINDOWS AND SCREENS: Whether used separately or in combination, aluminum storm windows and screens offer the advantages of light weight for easy installation, permanent fit with no swelling and shrinking problems, resistance to rust and corrosion, attractive appearance and minimum maintenance. Many standard makes are available. Where the climate does not require storm windows, roll-up and tension screens are of advantage. Standard combination storm and screen doors are also available in aluminum.

SHUTTERS: Aluminum shutters eliminate problems of rotting, warping, splitting and rusting. They can be finished permanently in various aluminum tones that do not require repainting, or they can be painted where it is desired.

7.15 SCREEN PORCH ENCLOSURES

Extruded aluminum screen porch enclosures are strong, lightweight units which require practically no maintenance. The members are narrow, providing minimum obstruction to view.

The fittings are designed so that the entire enclosure can be removed and stored for winter. This is optional since the aluminum will not deteriorate if left exposed the year around. The bottom panels of screens may be reinforced with standard aluminum guards, or the bottom rail can be increased in height to align with the bottom rail of the screen door.

The spline is roll-formed aluminum to permit replacement of wire cloth in case of damage. Figure 7-77 shows a typical porch enclosure.

7.16 GLASS ENCLOSURES, SKYLIGHTS, PENTHOUSES

Extruded aluminum sections are ideal as glazing bars of glass enclosures for greenhouses, solariums, aviaries, indoor swimming pools and tennis courts, sewage treatment plants, glass roofs and the like. Usually employed with hot-dip galvanized steel structural members, they constitute a maintenance-

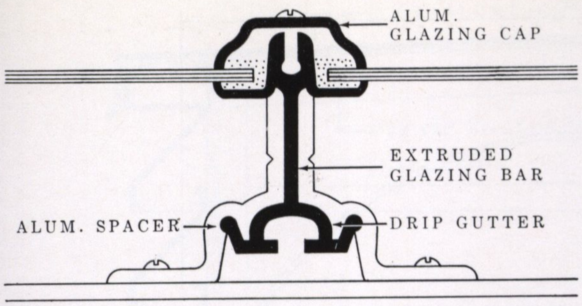
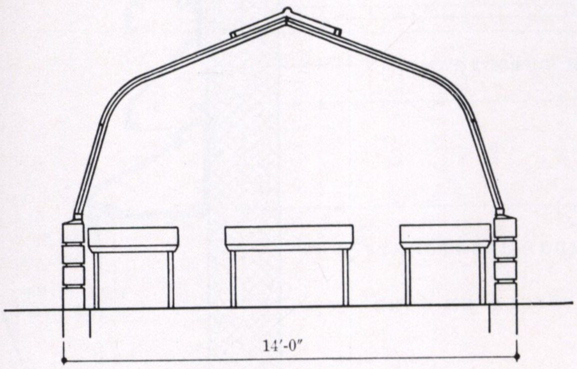


Figure 7-78: Extruded glazing bar.



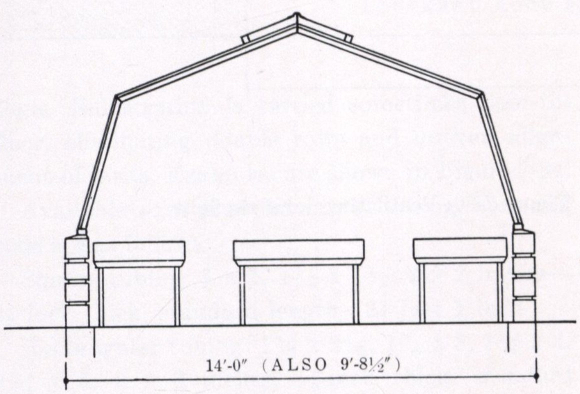


Figure 7-79: All-aluminum standard greenhouses.

free construction.

Figure 7-78 shows a glazing bar with integral gutter for carrying off condensation. The bar is mounted free from the structural member by means of an aluminum bracket so that there will be no heat transfer.

This manufacturer also produces glass enclosures in three standard spans: 18 feet, 21 feet 6 inches and 25 feet. There is great variety in greenhouse design including curved eaves. All-aluminum standard greenhouses are also available in spans up to 14 feet with ridge-hung vent sash running the full length of the roof. Two of the standard products are shown in Figure 7-79. A standard all-aluminum lean-to of similar design is also obtainable.

In addition to conventional skylight construction of glass and extruded aluminum sections, roof dome units are being used increasingly in schools, factories, residences and the like. These units consist of a translucent material in a complete frame of extruded aluminum ready to fasten to the roof deck and with provisions for flashing.

One company uses a slightly domed translucent corrugated fiber-glass panel. Others use clear or translucent plastic domes. The domes are single or double. The aluminum unit is either fixed or manually opened for ventilation, or serves as a roof hatchway. Sometimes it is combined with a built-in mechanical air exhaust (see Figure 7-80).

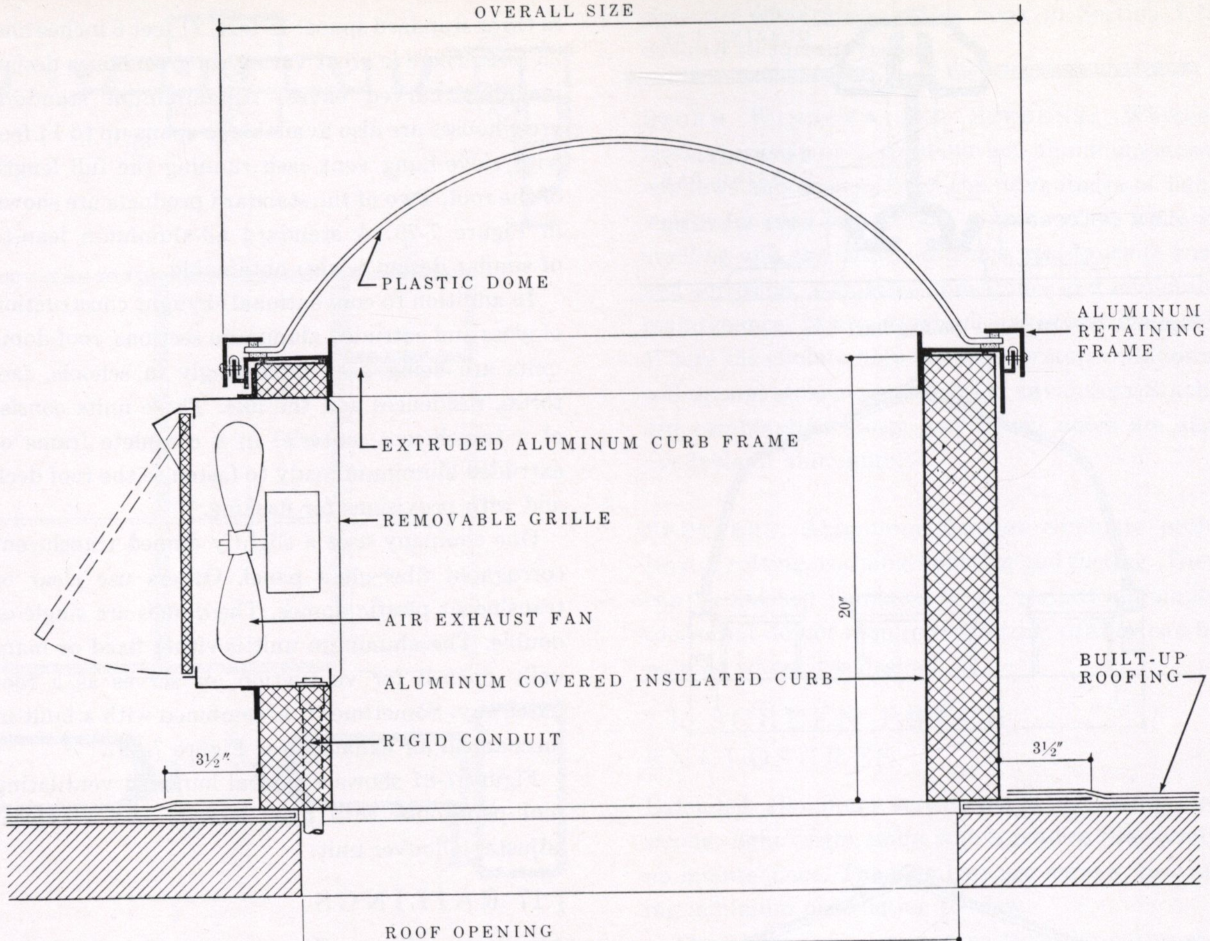
Figure 7-81 shows a typical louvered ventilating roof penthouse with fixed louvers and a typical adjustable louver unit.

7.17 RAILINGS

Aluminum railings offer a great variety in design and application on an economical basis and a practically maintenance-free installation.

PIPE RAILINGS: These are ideal for heavy-duty applications in service areas. The pipe is available in nominal sizes of 1, 1¼, 1½ and 2 inches and in standard lengths of 20 feet. The commonly used nominal sizes are 1¼-inch (1.38-inch inside diameter, 1.66-inch outside diameter, .14-inch thickness) and 1½-inch (1.61-inch inside diameter, 1.90-inch outside diameter, .145-inch thickness). The recommended post spacing is 5 feet 8 inches for the 1¼-inch size and 7 feet between posts for the 1½-inch size pipe.

Aluminum pipe railing can be erected economically in view of the availability of flush fittings such as those shown in Figure 7-82. These not only provide speed of erection, but also produce a crisp,



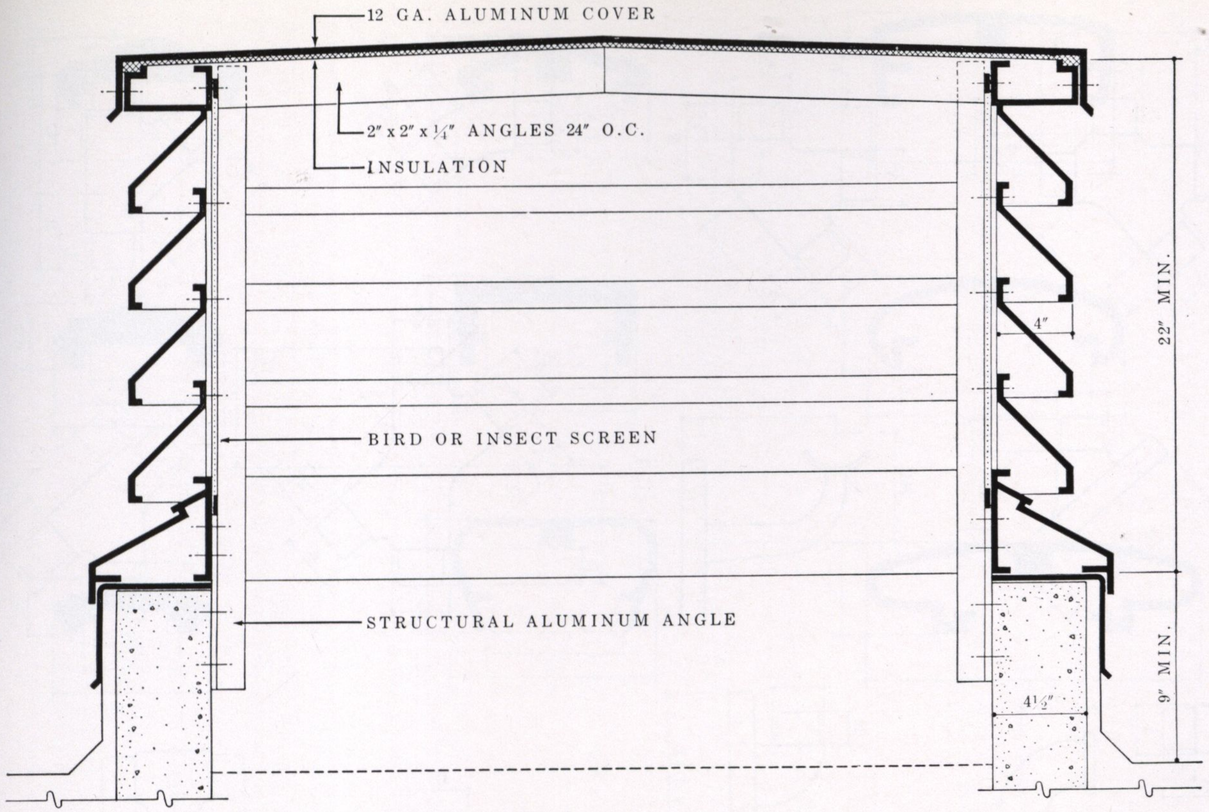
OVERALL SIZE	ROOF OPENING
20⅛ x 20⅛	16 x 16
24⅞ x 24⅞	20¾ x 20¾
36⅛ x 36⅛	32 x 32
52⅛ x 52⅛	48 x 48
20⅛ x 28⅛	16 x 24
31⅜ x 95⅜	27¼ x 91¼
36⅛ x 52⅛	32 x 48
60⅞ x 60⅞	56¾ x 56¾
63⅜ x 75⅜	59¼ x 71¼
63⅜ x 95⅜	59¼ x 91¼

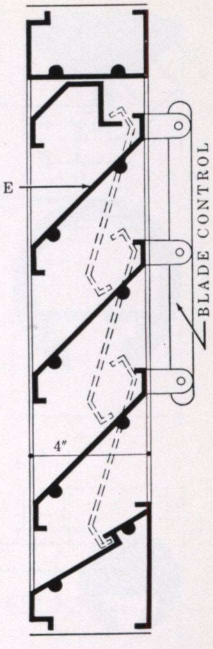
Figure 7-80: Ventilating dome skylight.

projection-free railing of excellent appearance.

ORNAMENTAL RAILINGS: Standard handrails are available in a great variety of sections to suit design conditions. Figure 7-83 shows some typical standard sections and wall brackets. Handrail sections are supplied in 20-foot lengths.

The combination of handrails with balusters made of square, rectangular or round tubing or bars can produce a variety of architectural solu-





tions. Balustration is carried sometimes floor-to-floor, eliminating double rows and uneven alignment of posts. Examples are shown in Figure 7-84.

Available sizes of architectural tubing, bars and rods are as follows:

Square tubing: 1 x 1, 1½ x 1½, 2 x 2 inches—⅛-inch thick, standard length—21 feet 1 inch

Rectangular tubing: 1¾ x 2¼, 1¾ x 3, 1¾ x 4, 1¾ x 5, 2 x 3 inches, ⅛-inch thick, standard length—21 feet 1 inch

Round pipe: 1, 1¼, 1½, 2 inches diameter, standard length—20 feet

Square bar: ½ x ½, ⅝ x ⅝, ¾ x ¾, 1 x 1, 1¼ x 1¼, 1½ x 1½ inches, standard length—16 feet

Rectangular bar: ⅛ x ½ to 2, 3/16 x ½ to 2½, ¼ x ½ to 3, ⅜ x ½ to 3, ½ x ¾ to 3, ¾ x 1½, ¾ x 2, 1 x 1½, 1 x 2 inches, standard length—16 feet

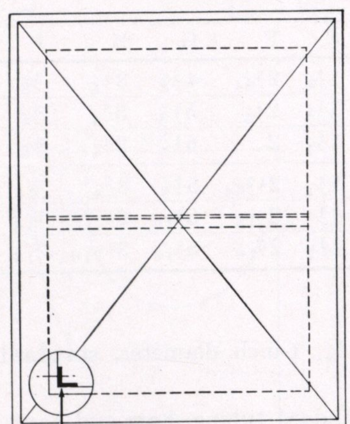
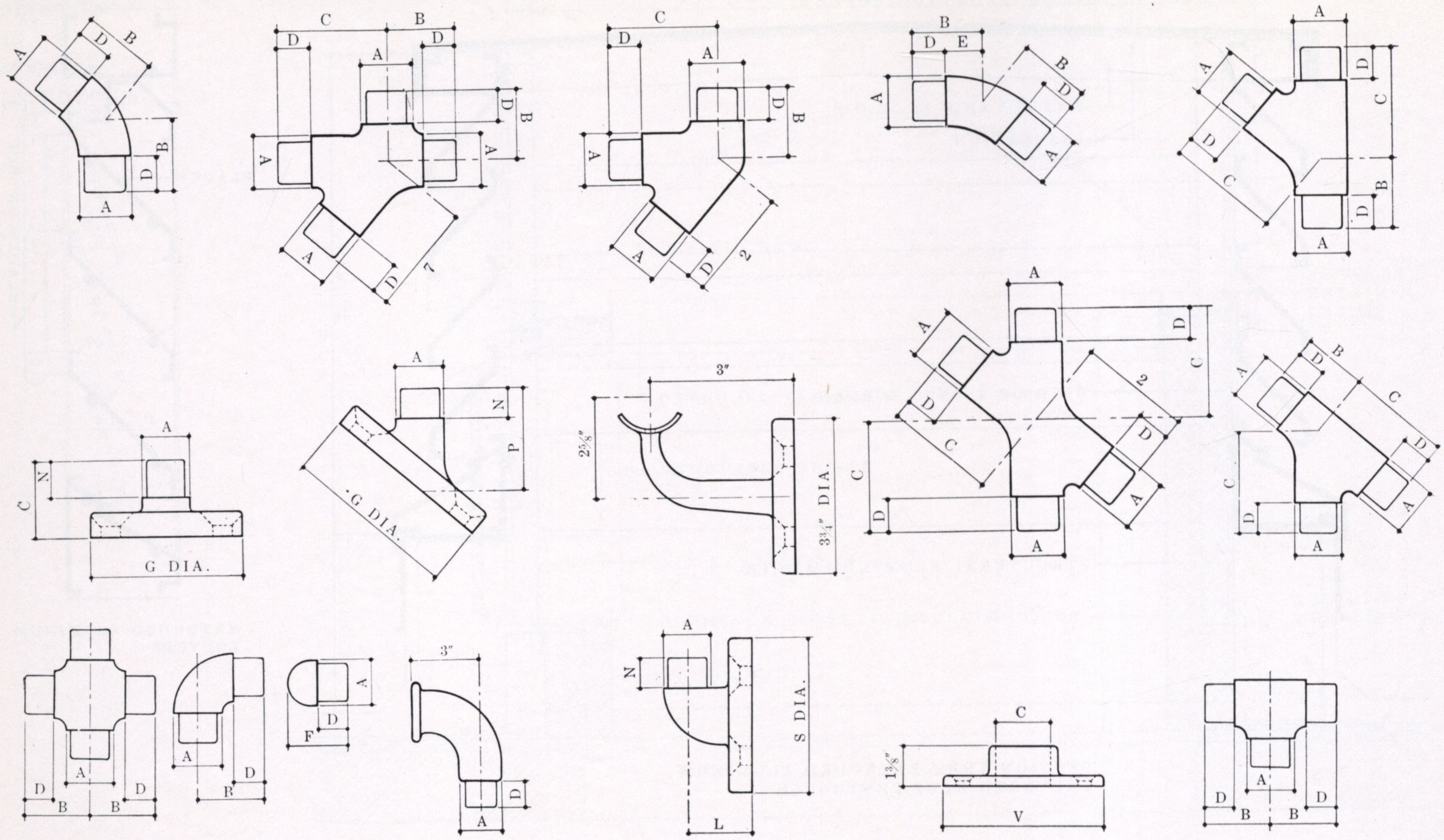


Figure 7-81: Details of a ventilating penthouse.



PIPE SIZE INCHES	FIT-TINGS	DIMENSIONS—INCHES A	B	C	D	E	F	G	H	J	K	L	M	N	R	S	T	U	V
1 1/4	90°	1 21/32	2 1/2	3 1/16	1 1/4	1 1/4	2 5/64	4 5/8	3 1/4	3/8	9/16	1 13/16	1	2 1/16	3 15/16	5 5/16	2 1/8	1 43/64	4 7/8
	40°	1 21/32	2 1/2	3 1/2	1 1/4	1 1/4	2 1/4	5 1/8	3 3/4	3/8	9/16	2 1/8	2 1/16	2	4 3/16				
	35°	1 21/32	2 1/2	3 1/4	1 1/4	1 1/4	2	5 1/8	3 3/4	3/8	9/16	1 13/16	2 1/16	2	3 7/8				
1 1/2	90°	1 29/32	2 3/4	3 1/2	1 1/4	1 1/2	2 13/64	5 1/8	3 3/4	7/16	9/16	1 29/32	1 1/16	2 7/16	4 1/4	5 5/8	2 13/32	1 59/64	5 3/16
	40°	1 29/32	2 3/4	3 13/16	1 1/4	1 1/2	2 9/16	5 5/16	3 15/16	7/16	9/16	2 1/4	2 7/16	2 3/32	4 11/16				
	35°	1 29/32	2 3/4	3 9/16	1 1/4	1 1/2	2 5/16	5 5/16	3 15/16	7/16	9/16	2 1/16	2 7/16	2 3/32	4 1/2				

Figure 7-82: Flush type pipe-rail fittings.

Round rod: ½, ¾, 1-inch diameter, standard length—16 feet.

In addition to standard tubing, bars and hand-rails, other aluminum components are available to fabricators. These include shaped balusters, brackets, grilles and other accessories that can be combined with materials such as glass, plastics, wood and the like. Figure 7-85 shows examples of typical assemblies of such components.

BRIDGE RAILINGS: Use of aluminum alloys for bridge railings means the elimination of costly maintenance. It also permits great latitude in design using made-to-order extrusions and economical fabricating methods. Figure 7-86 shows a horizontal parapet railing and a vertical type railing.

Figure 7-87 illustrates two methods of anchoring posts into concrete. The post at left is secured with anchor bolts set into concrete during pouring opera-

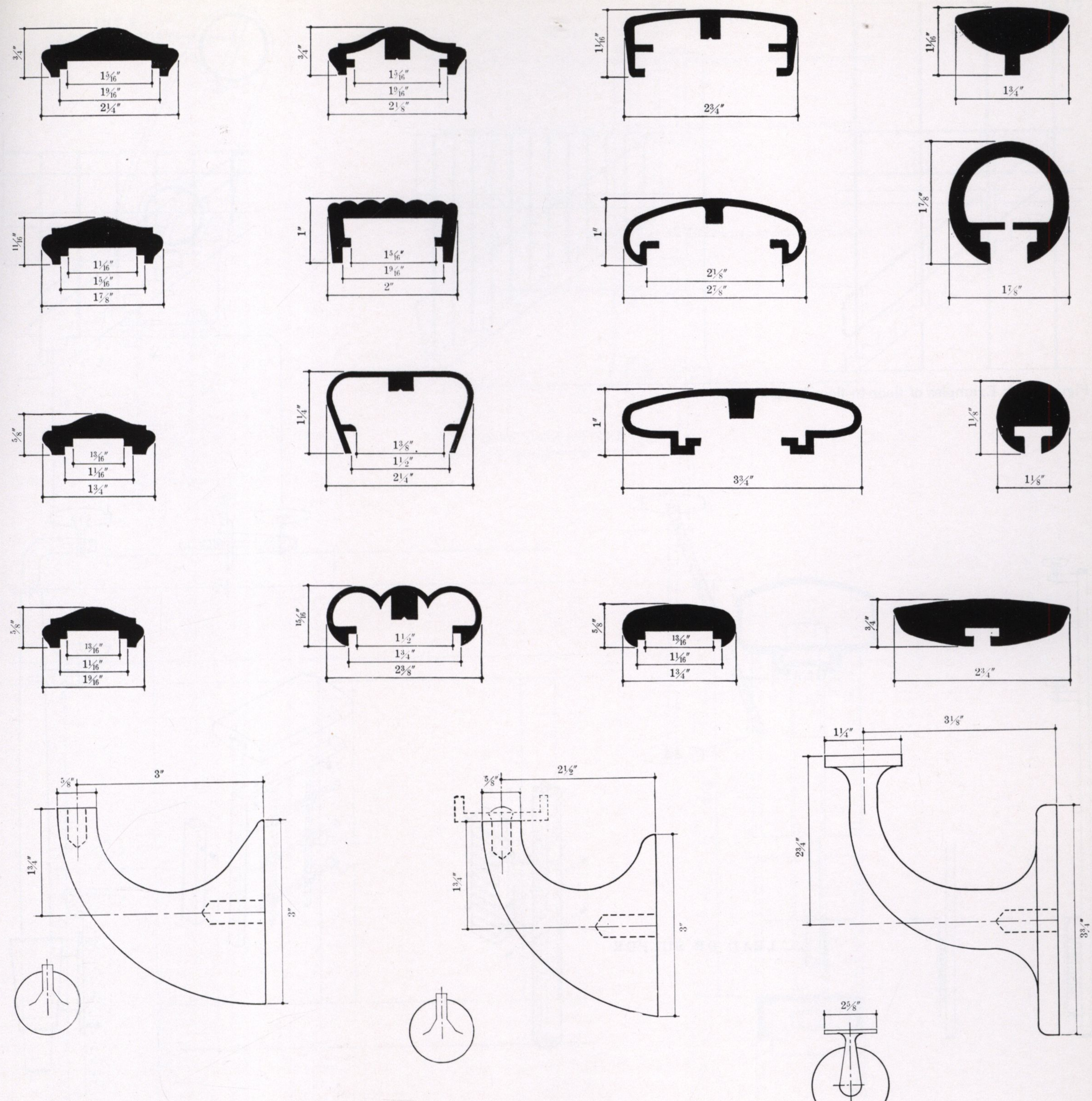


Figure 7-83: Standard ornamental railing sections and brackets.

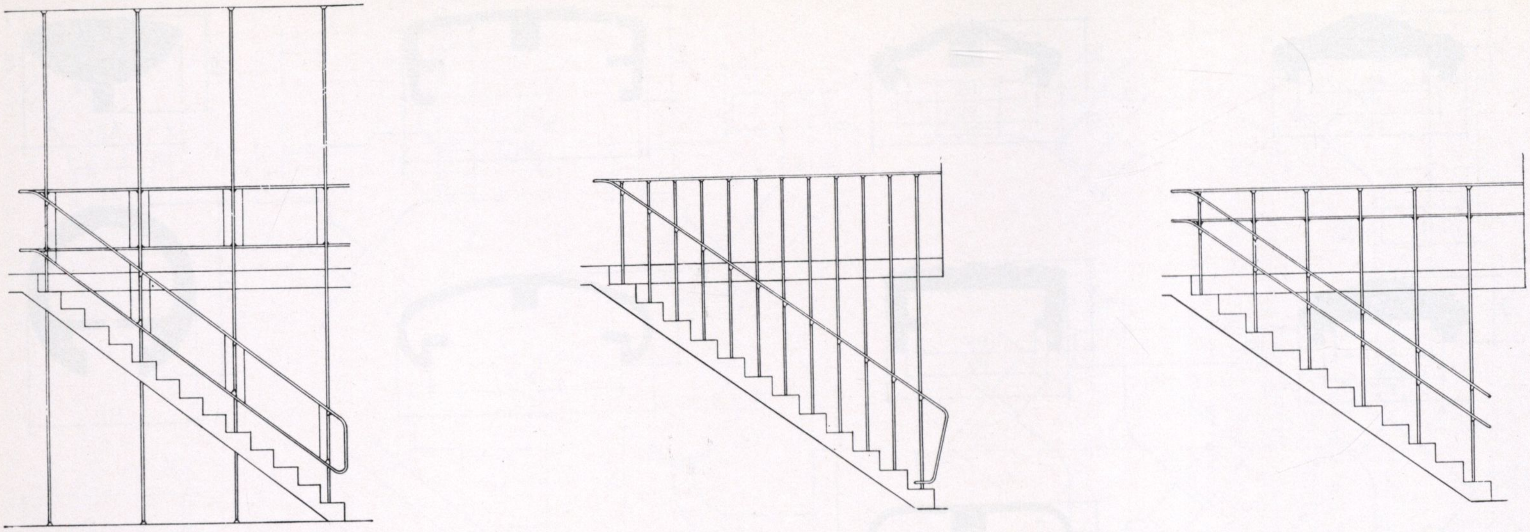


Figure 7-84: Examples of floor-to-floor balustration.

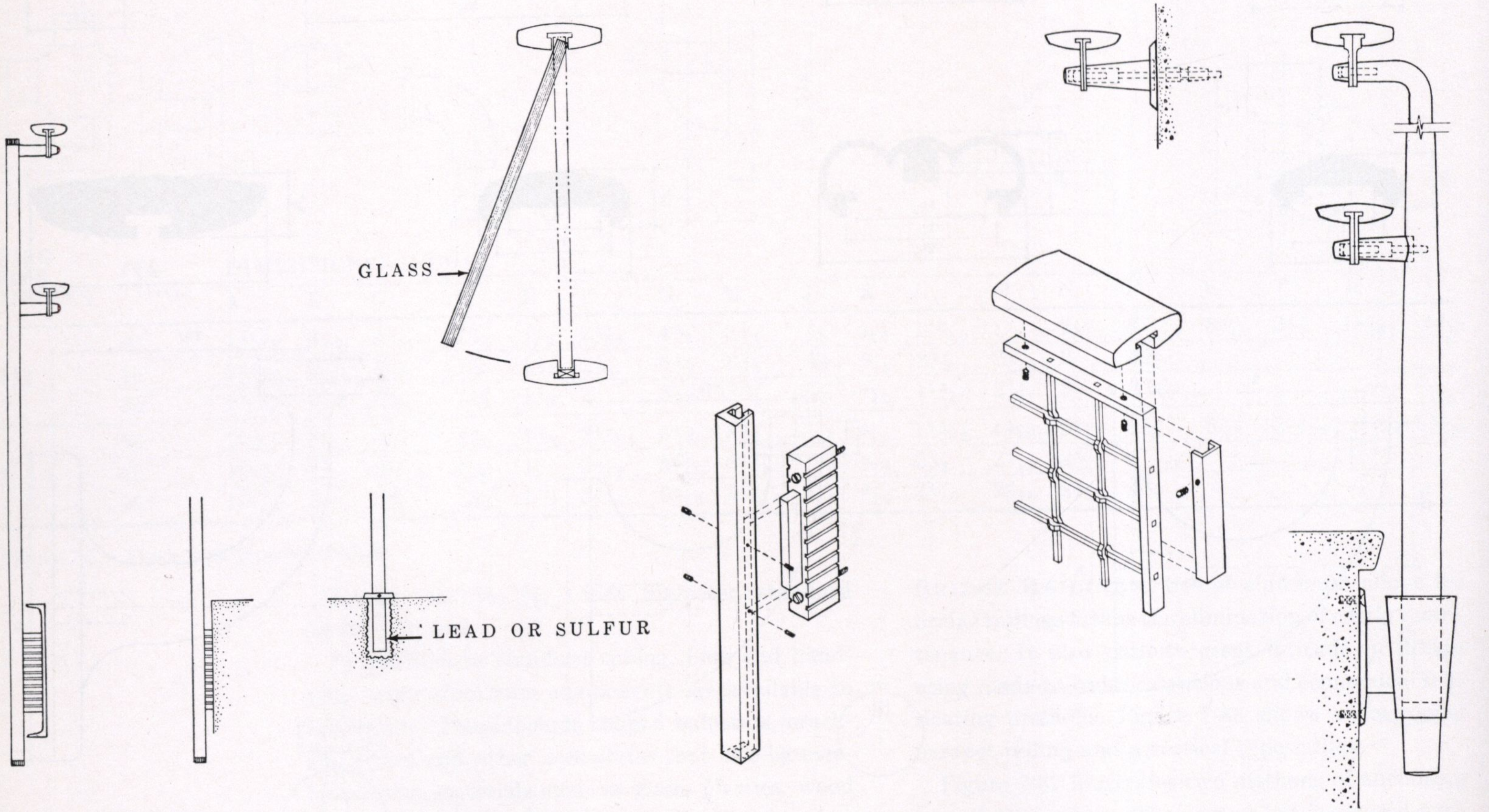


Figure 7-85: Examples of assemblies of ornamental railings.

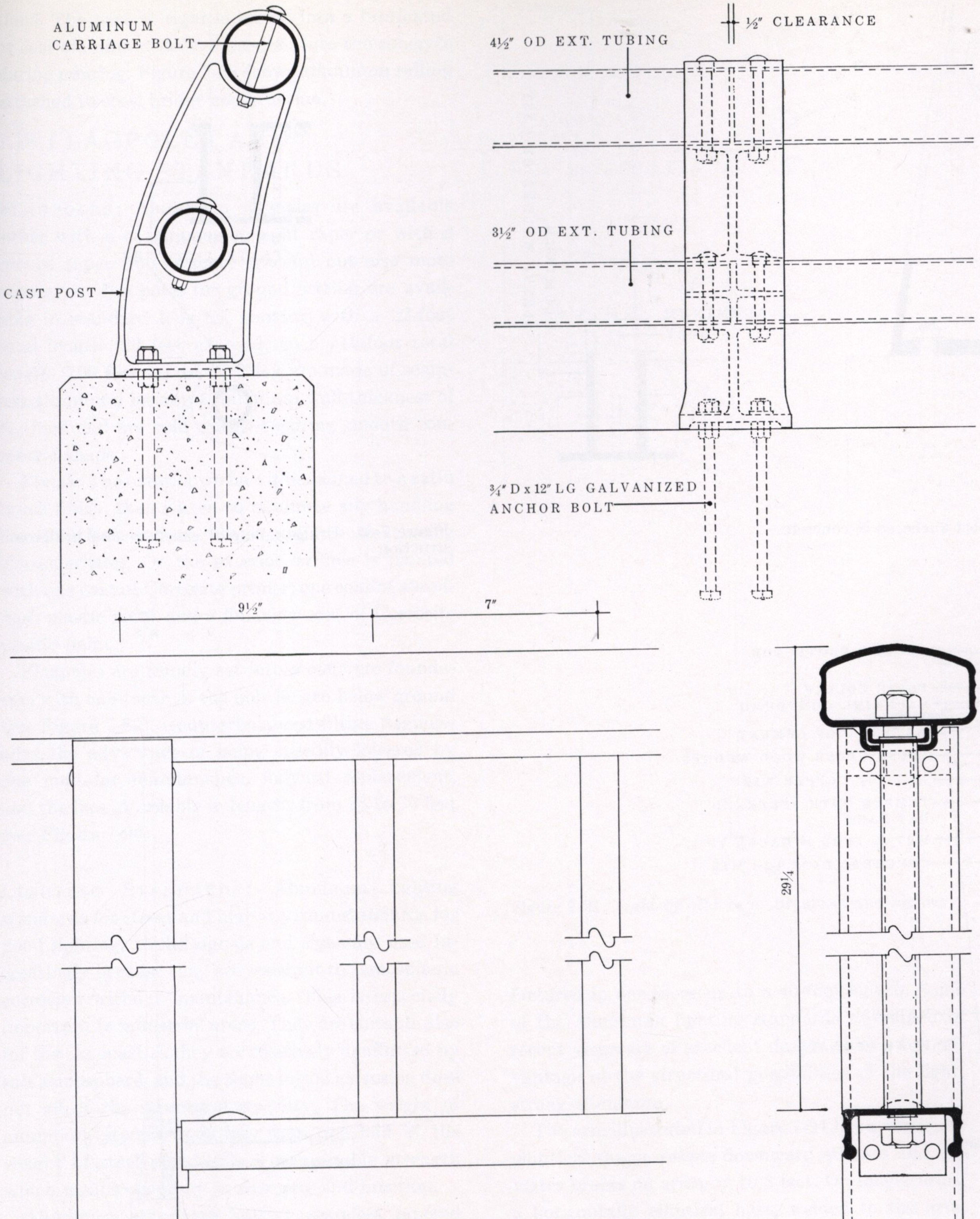


Figure 7-86: Horizontal parapet railing and vertical type railing.

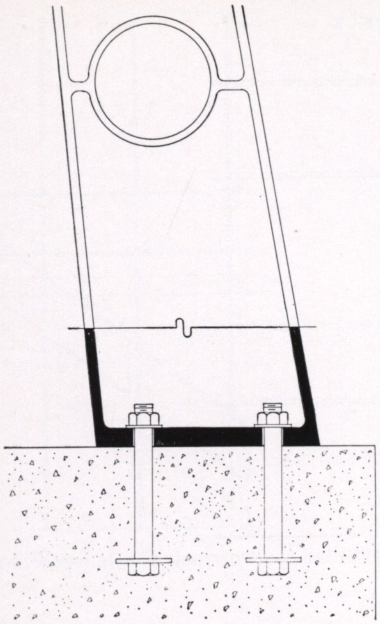


Figure 7-87: Bridge railing post anchored in concrete.

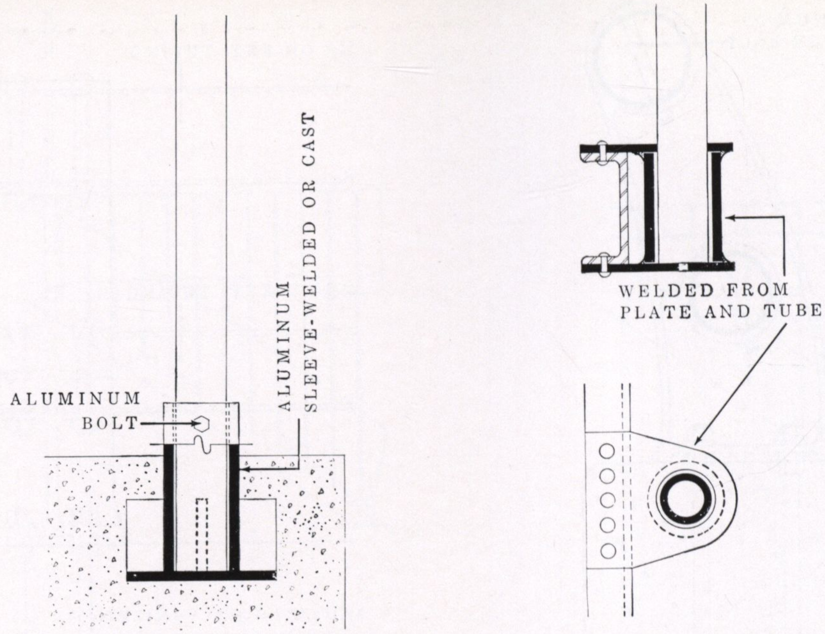


Figure 7-88: Bridge railing attached to steel bridge construction.

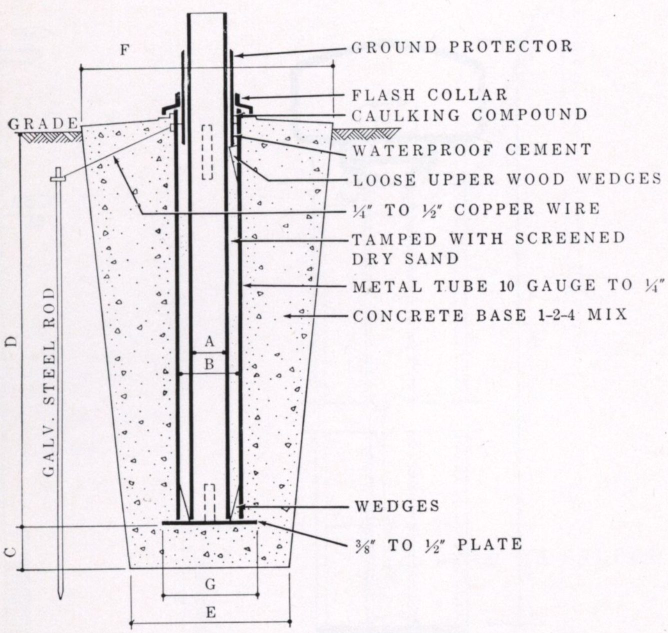


Figure 7-89: Flagpole foundation.

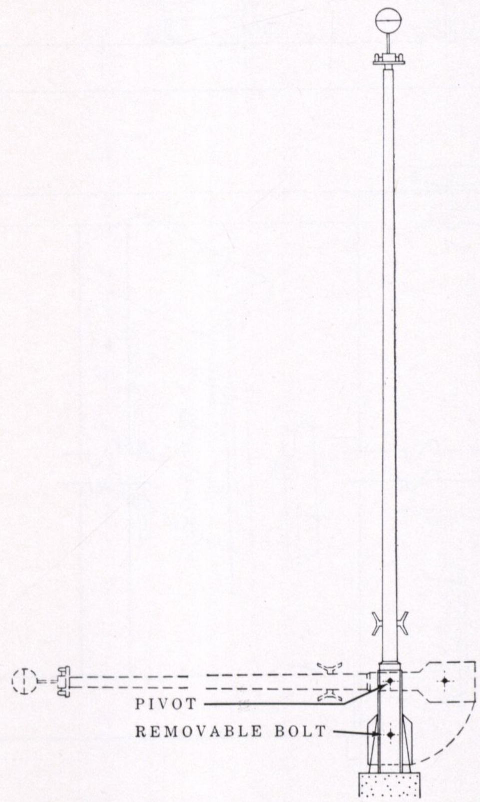


Figure 7-90: Counterbalanced tilting flagpole.

tions. The post at right is bolted into a fabricated or cast aluminum sleeved base set into the concrete during pouring. Figure 7-88 shows aluminum railing attached to steel bridge construction.

7.18 FLAGPOLES AND LIGHTING STANDARDS

FLAGPOLES: Aluminum flagpoles are available either with a continuous straight taper or with a curved taper that is more graceful but also more expensive. The poles for ground setting are available in standard lengths, starting with a 22-foot total length (20 feet exposed) to a 110-foot total length (100 feet exposed). They are made of seamless aluminum having a minimum wall thickness of 3/16-inch and are cold rolled, ensuring smooth concentric shape.

Finish: The exterior surface is machined to a satin brush finish, then waxed to minimize any handling discolorations and to insure uniform weathering characteristics. Or the exterior surface is painted with one coat of Corrosite primer, one coat of aluminum plastic paint and a finishing coat of Corrosite plastic paint.

Flagpoles are usually set into a concrete foundation with one-tenth of the pole length below ground (see Figure 7-89). Counterbalanced tilting flagpoles offer the advantage of being speedily lowered by one man for maintenance, halyard replacement, and the like. Available in lengths from 25 to 70 feet (see Figure 7-90).

LIGHTING STANDARDS: Aluminum lighting standards for street and highway, and standards for flood lighting, traffic signals and signs are used increasingly because they are resistant to atmospheric corrosion without maintenance. This is especially important in industrial areas. They are suitable also for the sea coast as they are relatively unaffected by salt atmosphere, and the slight initial corrosion does not affect the structural stability. The weight of aluminum standards is less than one half of the weight of steel standards of comparable strength which means economy in shipping and erection.

Aluminum standards have a seamless tapered shaft, heat treated after fabrication. They are manufactured in one piece up to a 40-foot length. Some of the aluminum lighting standards developed in recent years are of excellent design, taking full advantage of the structural possibilities of the light, strong aluminum.

The arm illustrated in Figure 7-91 has a vertically elliptical shape, resists downward stresses and obviates braces on arms up to 8 feet. On longer arms, a horizontally elliptical base, welded to the arm, eliminates the need for side-bracing.

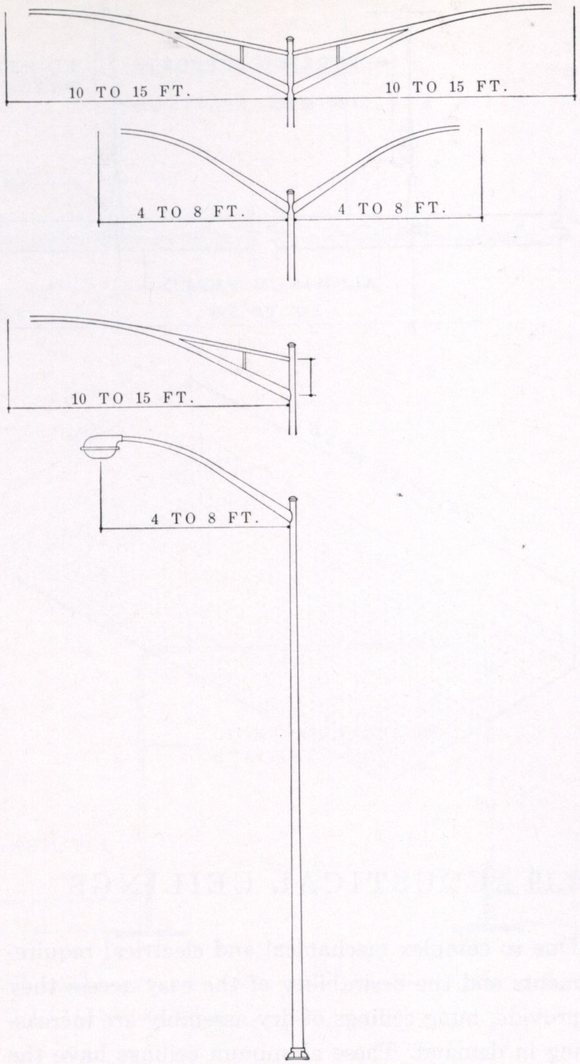


Figure 7-91: Lighting standards for street and highway.

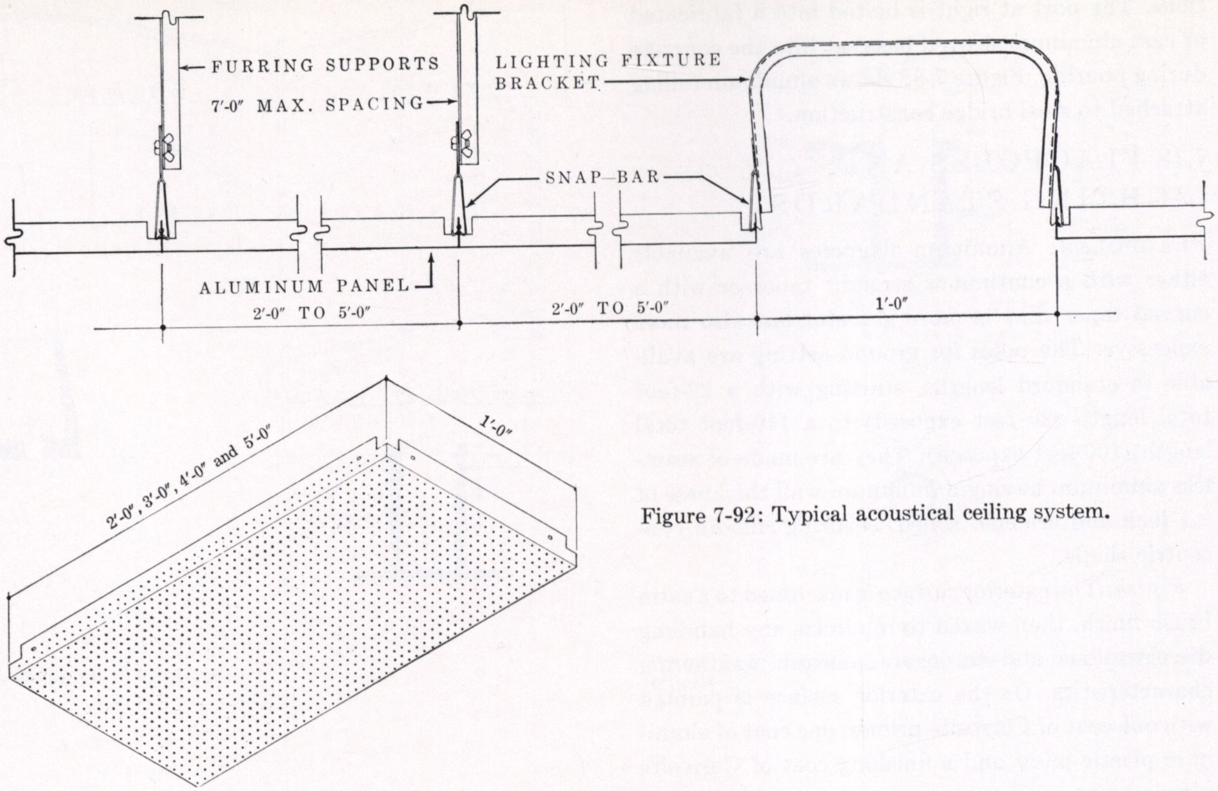


Figure 7-92: Typical acoustical ceiling system.

7.19 ACOUSTICAL CEILINGS

Due to complex mechanical and electrical requirements and the desirability of the easy access they provide, hung ceilings of dry assembly are increasing in demand. These aluminum ceilings have the advantage of light weight and low maintenance. They never need repainting and are easily cleaned.

Figure 7-92 shows a typical acoustical ceiling system. The perforated pans are 12 inches wide in lengths up to 60 inches, with beveled edges for fine line joints. The perforations are of .094-inch diameter on 1/4-inch straight centers. Panels are made of .025-inch thick sheets.

The pans are backed with acoustical pads of rock wool in flameproof envelopes or glass wool in moist areas, such as kitchens. The suspension system provides for combinations with recessed lighting. These panels are available also for use as integrated air ducts for heating or cooling.

Figure 7-93 illustrates a system manufactured by Reynolds Metals using corrugated perforated panels. This system consists of formed perforated aluminum panels supporting a glass fiber sound-absorbing blanket. The panels are either suspended on a system of supporting tees and angles, or are attached to the ceiling. Panels are available either corrugated or ribbed. The corrugated panels are formed to a 7/8-inch depth with a nominal 2.67-inch pitch with 1/8-inch perforations and spans up to 8 feet. Standard panel length are 6 and 8 feet. In corridors up to 12 feet wide, this ceiling is suspended entirely from the walls without intermediate overhead suspension.

The ribbed pyramid panels are formed to 3/8-inch depth with a nominal 1 1/2-inch pitch with .094-inch diameter perforations. Standard panel lengths are 4 and 5 feet. This panel is available also in 12-foot lengths for sidewall applications.

The panels have either a natural aluminum or painted white finish. The supporting tees are available in either white baked enamel or clear anodized

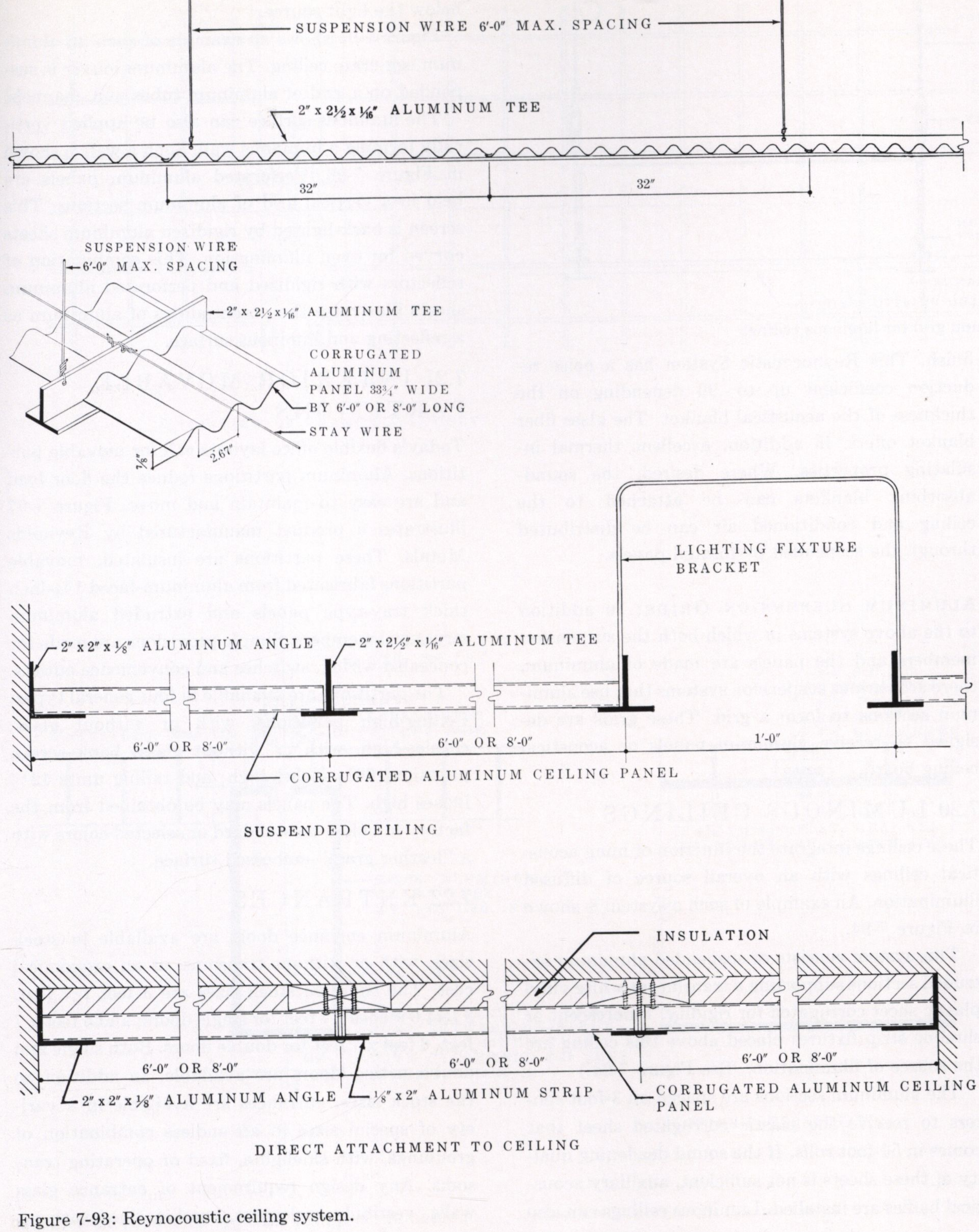


Figure 7-93: Reynocoustic ceiling system.

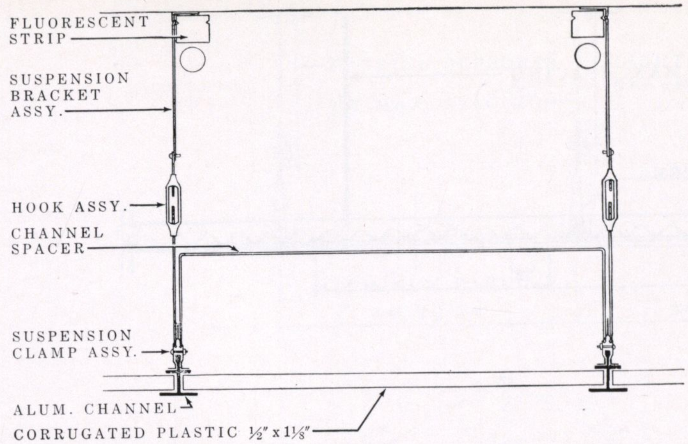


Figure 7-94: Suspended aluminum grid for luminous ceiling.

finish. This Reynocoustic System has a noise reduction coefficient up to .90 depending on the thickness of the acoustical blanket. The glass fiber blanket offers, in addition, excellent thermal insulating properties. Where desired, the sound-absorbing blankets can be attached to the ceiling and conditioned air can be distributed through the suspended perforated panels.

Aluminum Suspension Grids: In addition to the above systems in which both the suspension members and the panels are made of aluminum, there are various suspension systems that use aluminum sections to form a grid. These grids are designed to receive aluminum panels or acoustical ceiling board.

7.20 LUMINOUS CEILINGS

These ceilings integrate the function of hung acoustical ceilings with an overall source of diffused illumination. An example of such a system is shown in Figure 7-94.

This system consists of suspended aluminum extruded sections supporting a translucent white vinyl plastic sheet corrugated for rigidity. Fluorescent or slimline strip fixtures placed above this ceiling are the source of illumination. (See Figure 7-94.)

The aluminum sections are spaced on 3-foot centers to receive the plastic corrugated sheet that comes in 50-foot rolls. If the sound deadening quality of these sheets is not sufficient, auxiliary acoustical baffles are installed. Luminous ceilings can also be installed by suspending an egg-crate louver below the light source.

Figure 7-95 shows an example of such an aluminum egg-crate ceiling. The aluminum louver is suspended on a grid of aluminum tubes and channels.

The luminous surface can also be applied vertically forming a luminous wall. Such a wall is shown in Figure 7-96. Perforated aluminum panels are held in a vertical grid of aluminum sections. This screen is back-lighted by rigidized aluminum sheets curved for even illumination. This combination of reflectors with rigidized and perforated aluminum sheets illustrates the potentialities of aluminum as a reflecting and luminous surface.

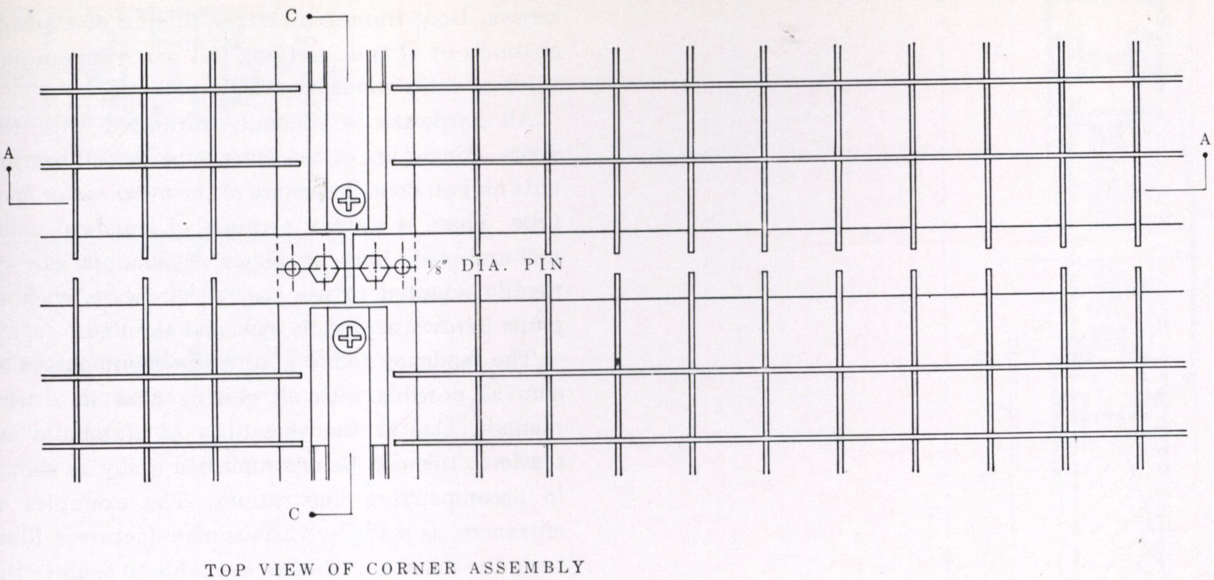
7.21 INTERIOR MOVABLE PARTITIONS

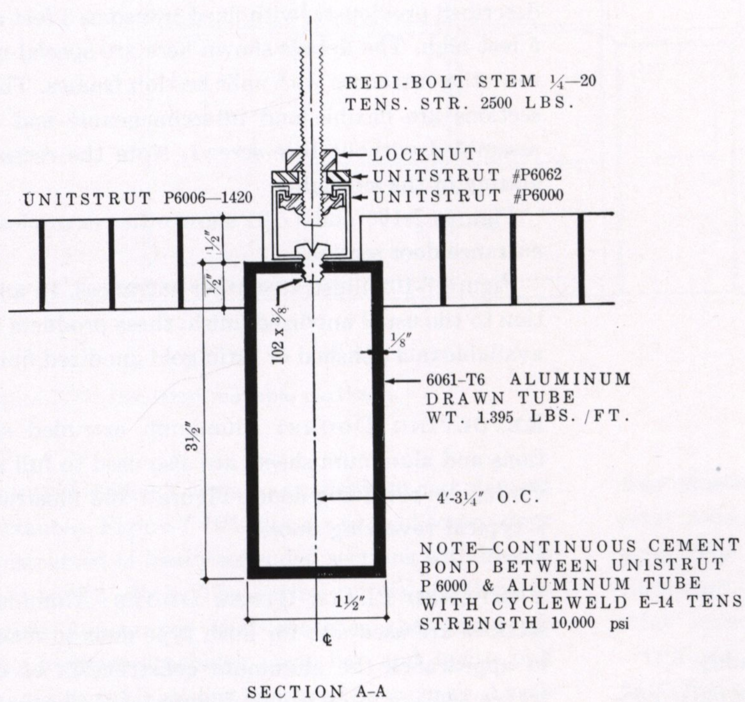
Today's flexible office layouts call for movable partitions. Aluminum partitions reduce the floor load and are easy to maintain and move. Figure 7-97 illustrates a product manufactured by Reynolds Metals. These partitions are insulated, movable partitions fabricated from aluminum-faced 1¾-inch thick tray-type panels and extruded aluminum structural members. Simple provisions are made for concealed wiring, switches and convenience outlets.

The partitions are available in four general types: Ceiling-high partitions, with or without glass; cornice-high, with or without glass; bank screen partitions 66¼ inches high; and railing units 42½ inches high. The panels may be obtained from the factory in baked-on standard or selected colors with a "leather grain" embossed surface.

7.22 ENTRANCES

Aluminum entrance doors are available in stock sizes, with or without transoms, at an economical cost. The common stock sizes are 3 feet x 7 feet, 3 feet 6 inches x 7 feet for single doors; and 5 feet x 7 feet, 6 feet x 7 feet for double doors. Both single and double-acting doors are available. In addition to the stock sizes, entrances are available in a variety of special sizes in an endless combination of groupings, with sidelights, fixed or operating transoms. Any design requirement of entrance glass walls, vestibule enclosures, combinations with re-





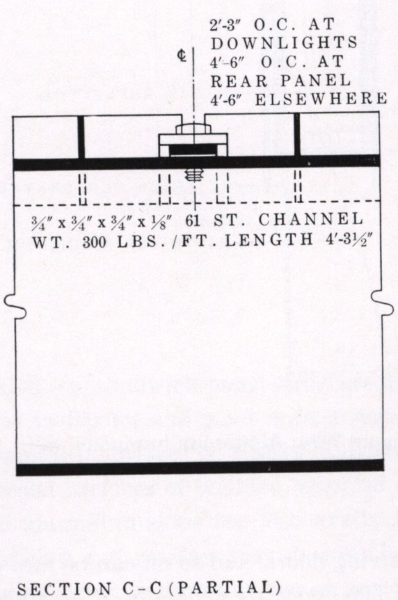


Figure 7-95: Aluminum egg-crate ceiling.

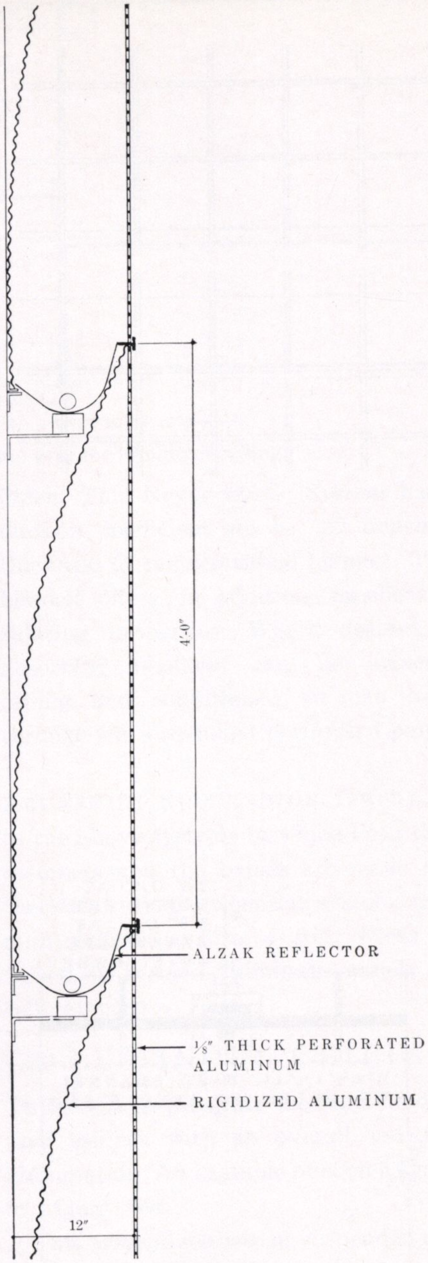


Figure 7-96: Aluminum luminous wall.

volving doors, and so on can be met readily.

The doors are generally of seamless tubular construction, welded, with all reinforcing at corners, and with hardware concealed. All joints are milled to a hairline joint. Glazing is done without visible screws. Door frames are either tubular or made of channels or of split sections. All parts have a polished or satin anodized finish.

All hardware is generally furnished with the doors. Hinges are of the pivot type or ball-bearing butt hinges; door closers are of the overhead or floor type. There is usually a choice of standard pulls, pull-and-push bars or plates. Entrances can be readily adapted to use special hardware, such as panic hardware, electric eyes and the like.

The tendency today is to make the members as slim as possible with all glazing done in a trim manner. Due to the versatility of aluminum extrusions, this can be accomplished easily as shown in accompanying illustrations. The examples of entrances, as made by various manufacturers, illustrate the variety of choices available to achieve the desired appearance, and also suggest the possibilities for special designs. Figure 7-98 shows one line of standard entrances.

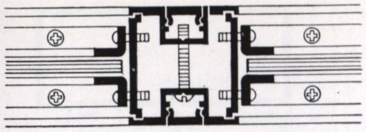
Figure 7-99 shows another line of entrances. This producer has a line of standard entrances of sizes described previously, with fixed transoms 3 feet and 5 feet high. The details shown here are special narrow stile entrances with split section frames. These sections are flexible and interchangeable and are assembled without face screws. Note the recessed glazing of the sidelights.

Figures 7-100 and 7-101 show other examples of entrance door sections.

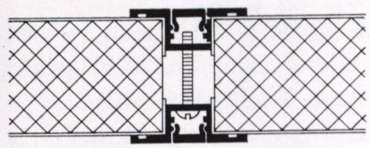
Figure 7-102 illustrates other entrances. In addition to the usual anodized finish, these products are available in a polished or satin gold anodized finish.

REVOLVING DOORS: Aluminum extruded sections and aluminum sheets are also used to full advantage in revolving doors. Figure 7-103 illustrates a typical revolving door.

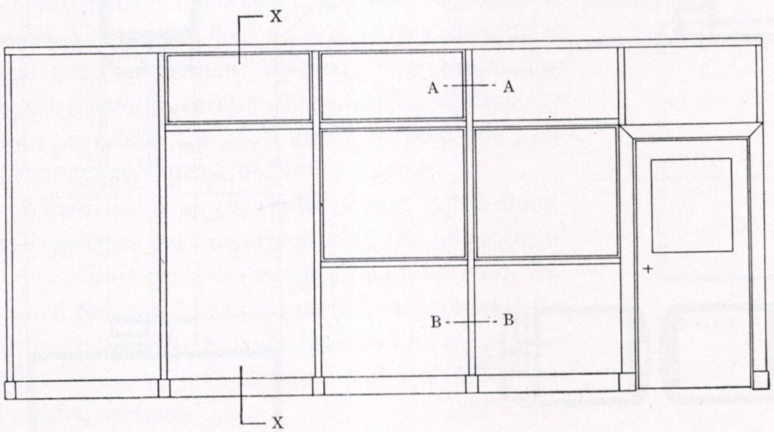
TEMPERED PLATE-GLASS DOORS: Aluminum sections are used also for flush type door to match in appearance the aluminum construction of entrance walls or store fronts. Figure 7-104 illustrates door sections. These doors are available in widths of 3 feet or 3 feet 6 inches for single doors and 5 feet or 6 feet for double doors.



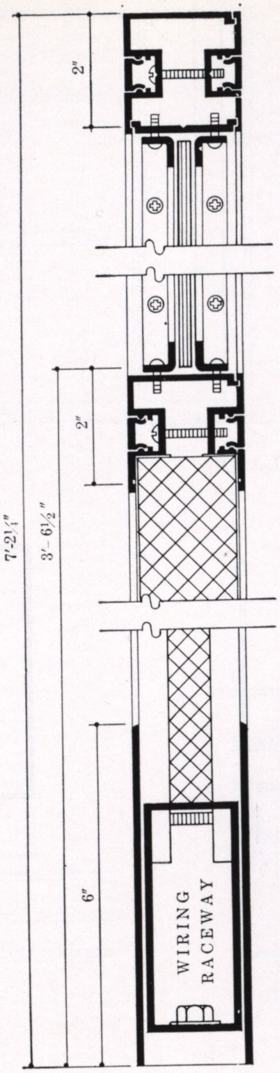
DETAIL A-A



DETAIL B-B



ELEVATION



SECTION X-X

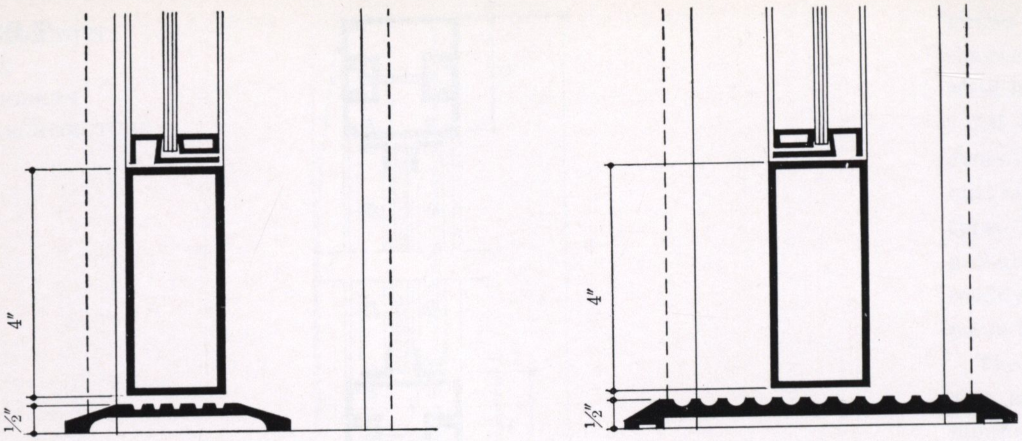
Figure 7-97: Insulated movable partition.

SCREEN DOORS are also available to complement entrances. Figure 7-105 shows a typical screen door constructed of heavy extruded sections with aluminum screen cloth. The entire unit is anodized to ensure appearance that matches the entrances. The hardware includes push bar and lucite pull handle, butt hinges and overhead door closer. Available only in stock sizes.

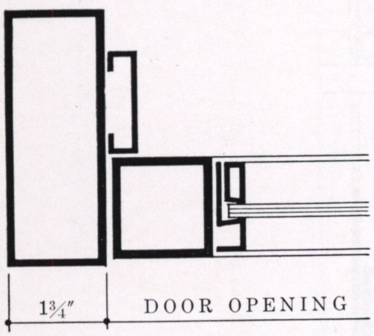
FLUSH DOORS: Figure 7-106 illustrates a flush door construction. Its sandwich panel structure has great resistance to flexure and good impact resistance. The standard surface is ribbed anodized aluminum. Special surfaces of pebbled, stippled or other textured aluminum skins are also available.

Optional piercing and glazing provide complete flexibility of installation and permit use on special units, within the following limitations:

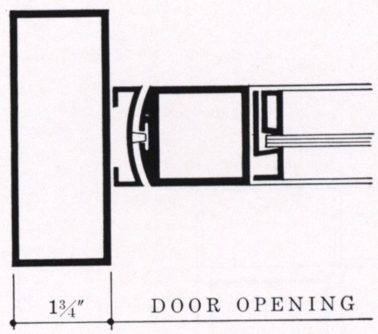
—One light that does not exceed one-third of the door area.



TYPICAL DOOR KICK PLATE AND THRESHOLDS

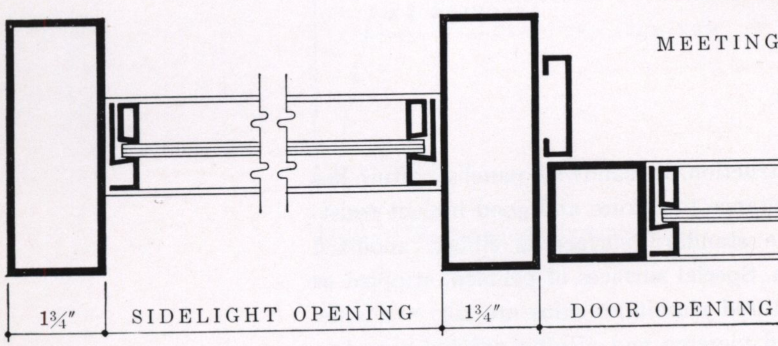


SINGLE ACTING

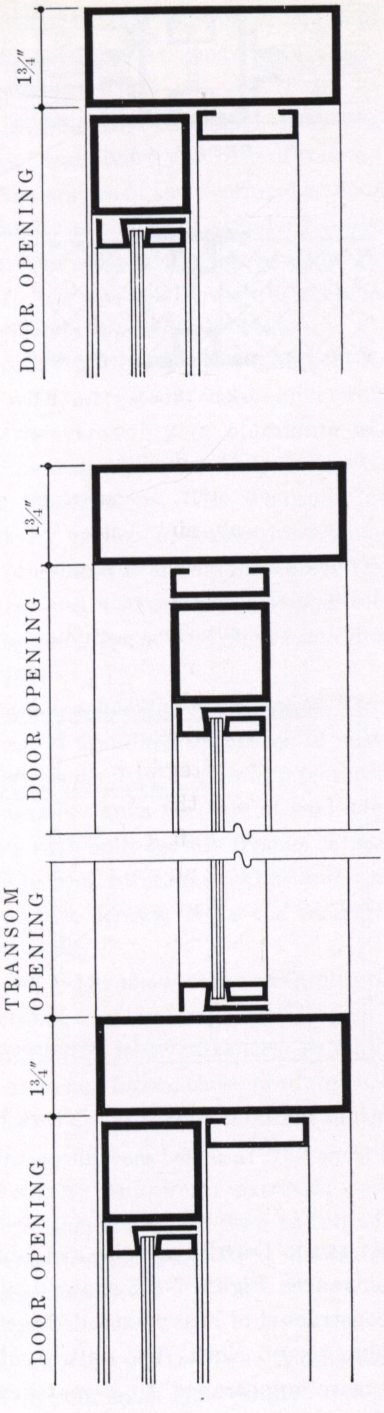


DOUBLE ACTING

MEETING RAILS



HORIZONTAL SECTIONS



TUBULAR FRAME CONSTRUCTION

VERTICAL SECTIONS

Figure 7-98: Standard entrances.

—Two lights that do not exceed one-half of the door area.
—Special size lights are not to be placed closer than 1 inch to the edge of the stile or 6 inches from the top or bottom.

7.23 STORE FRONTS

Modern store fronts strongly emphasize the impact of display on the public both in terms of show windows and the open front. In both cases, the emphasis is on making the glass barrier as inconspicuous as possible. In the case of the open front, the division between street and shop is reduced to the minimum. In line with this development in store design, store front construction has advanced accordingly.

Available aluminum store front sections and techniques facilitate the construction of store fronts that utilize large glass areas and incorporate all the wanted devices. The sections are narrow, without separate glazing moldings. If necessary, sections are recessed to provide flush glazing, letting the soffit or wall continue without marked interruption. The sections have integral resilient locking devices and grips that hold the glass firmly without the need for screws on the face of the store front.

Where cost is an important factor, rolled aluminum sections that incorporate all the advances of today's store front construction may be used. Extruded sections, somewhat more costly, provide the ultimate in sharp, straight lines and finish. Figures 7-107 through 7-113 show examples of rolled and extruded sections.

Figure 7-114 illustrates examples of trim moldings. These are used to cover fascias, columns, and as trim to receive other materials such as structural glass. The examples of sections and moldings illustrated represent only a fraction of the entire line of store front products, but they give an idea of the great variety and general characteristics of elements available to the designer as a working tool. Special sections and components, if needed, can be made at a relatively low cost.

7.24 SUN-CONTROL DEVICES

The marked trend toward larger glass areas in today's buildings makes sun control an increasingly

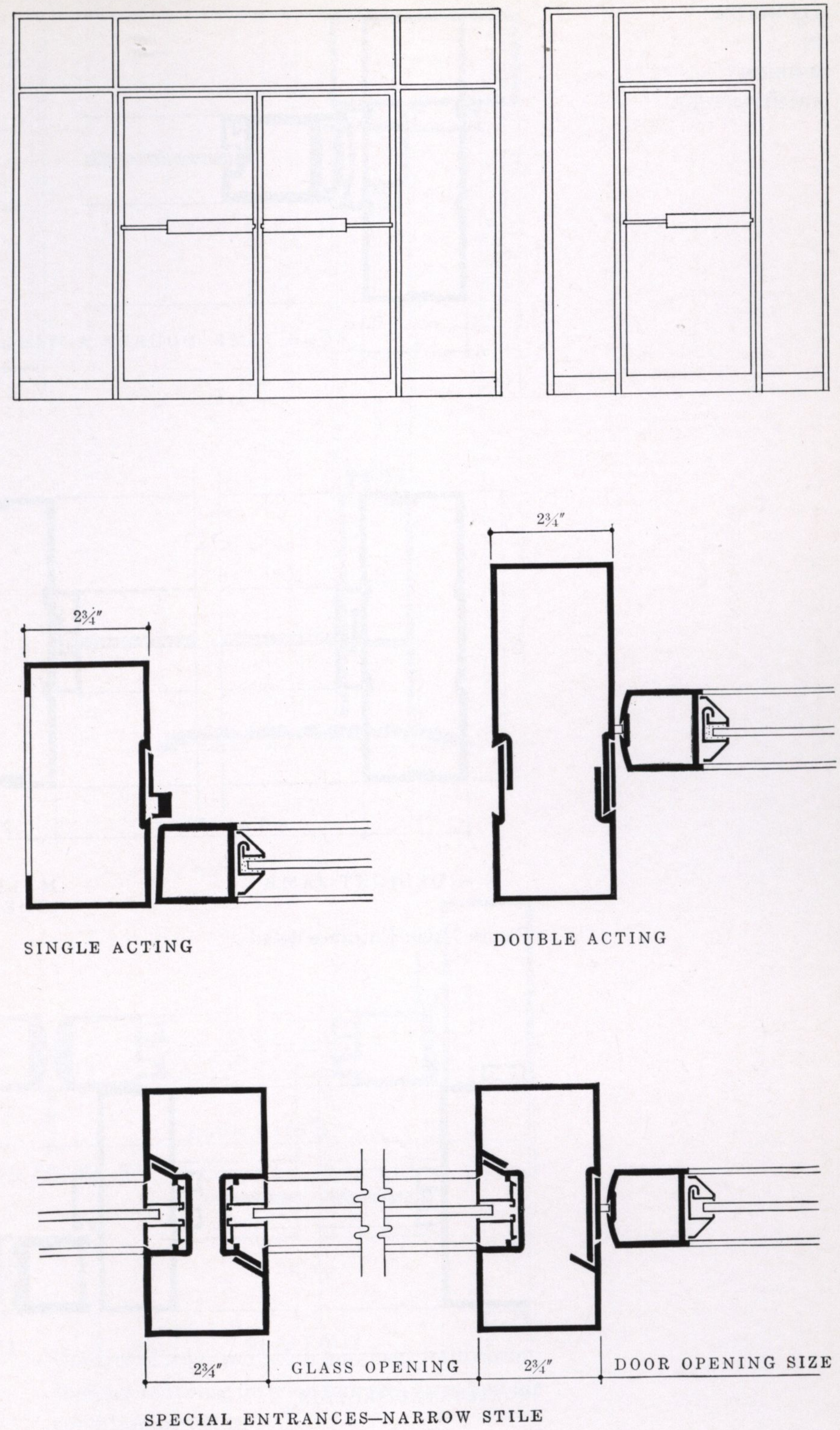


Figure 7-99: Examples of entrances with sidelights and transom.

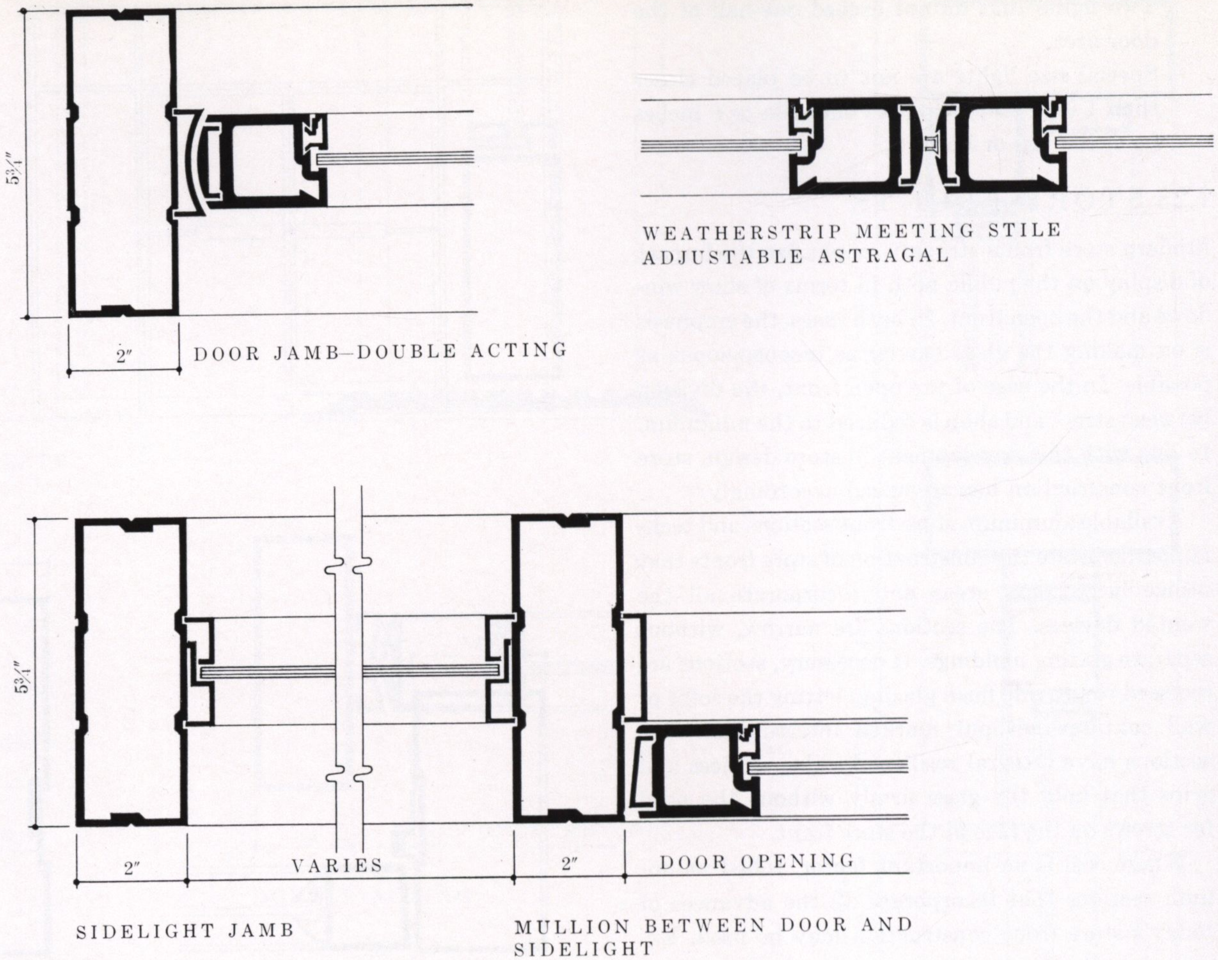


Figure 7-100: Entrance details.

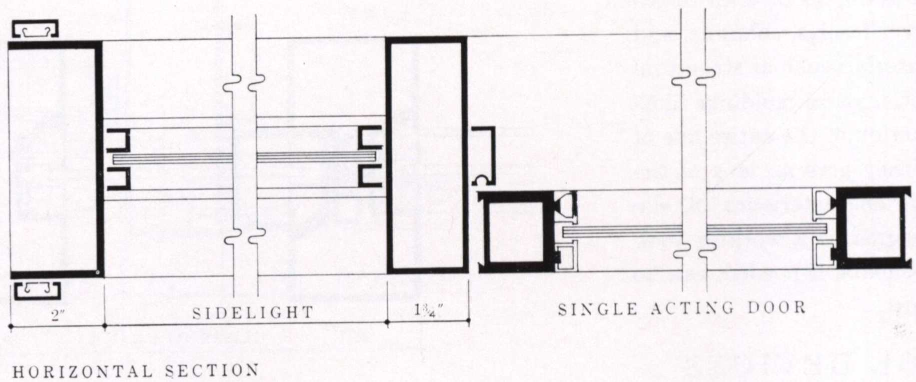


Figure 7-101: Entrance details.

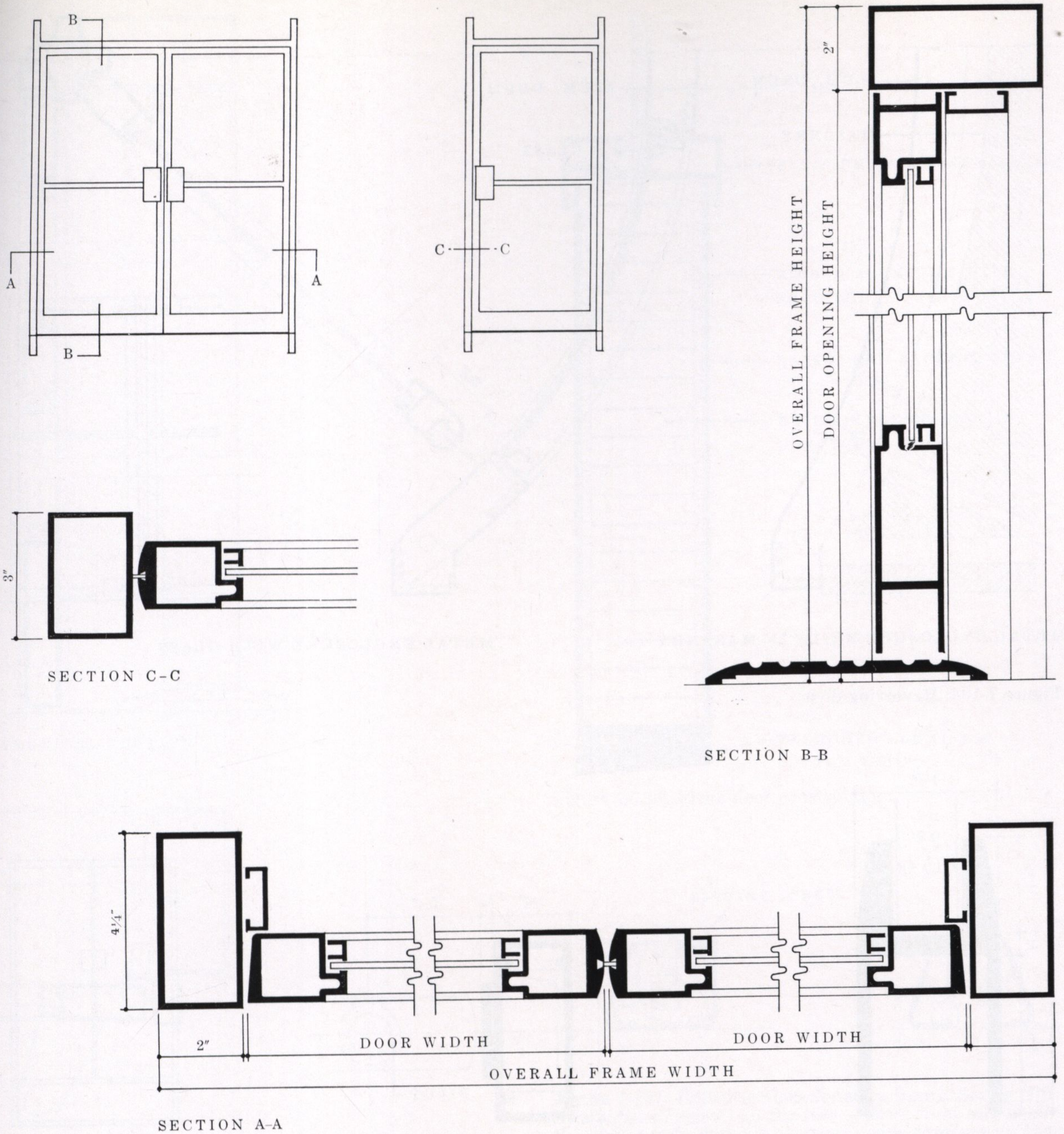


Figure 7-102: Entrance door, typical details.

important factor. Sun-control devices provide some of these advantages in various degrees and combinations:

—Protection from direct sunrays.

—Reduction of sky glare.

—Control of solar radiation and heat infiltration, thereby reducing interior temperatures and air conditioning loads.

—Weather protection.

—Protection of furnishings from bleaching and

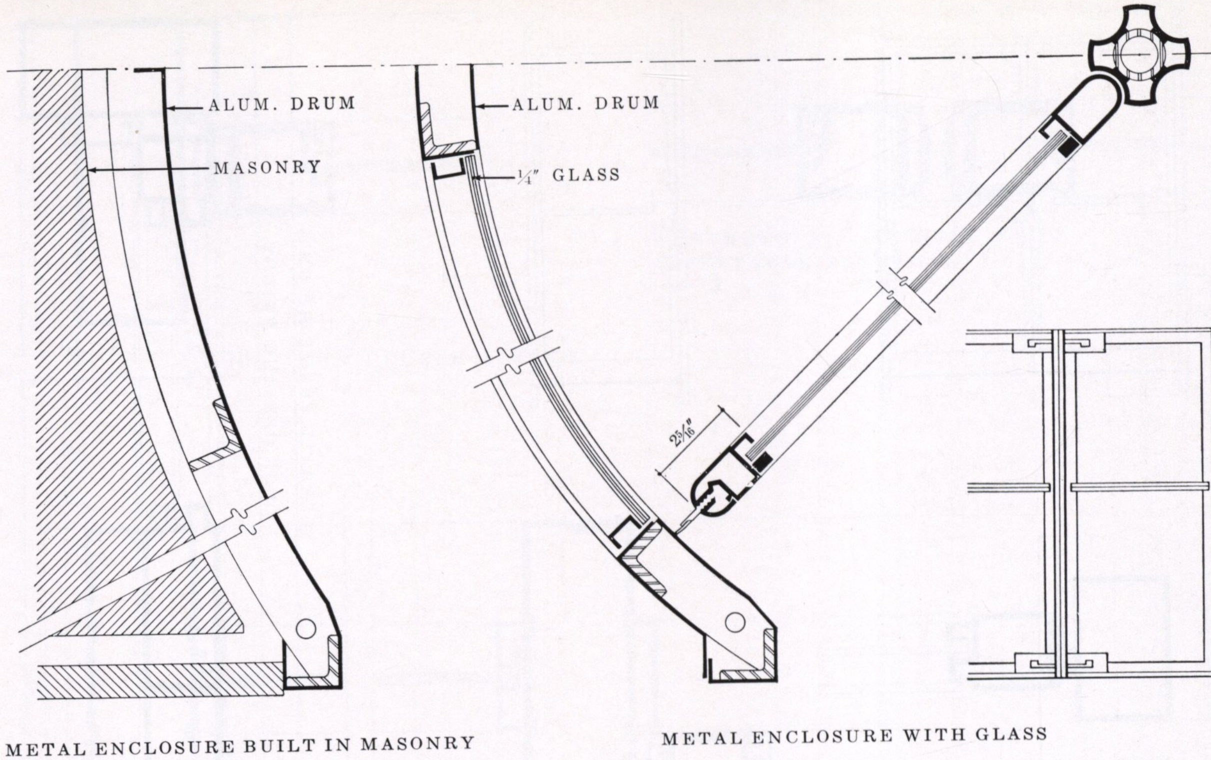


Figure 7-103: Revolving door.

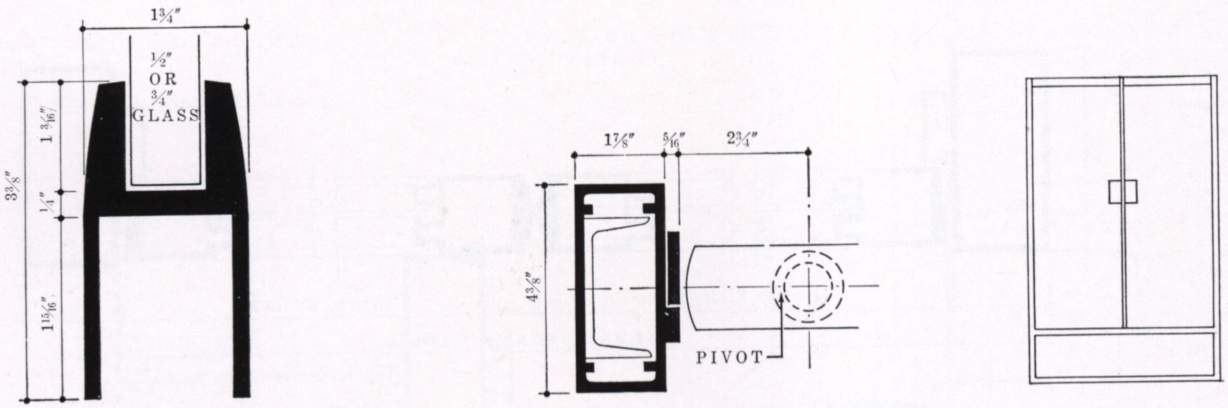


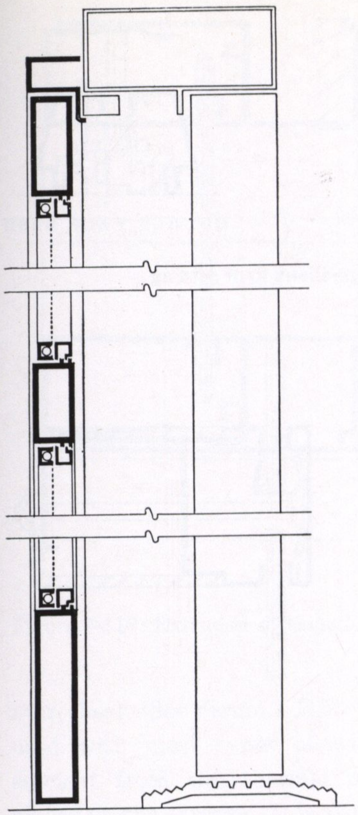
Figure 7-104: Tempered plate-glass door.

fading.

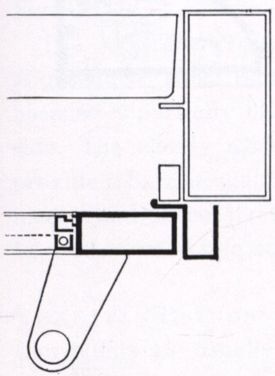
—Increased privacy.

—Elimination of need for drapes, shades and the like.

It is obvious that these advantages are important from the point of view of economy as well as the occupant's comfort and efficiency. Sun-control devices are of necessity exposed to the weather and often are complex. Maintenance charges on such items could easily become prohibitive unless they



VERTICAL SECTION



HORIZONTAL SECTION

Figure 7-105: Screen door details.

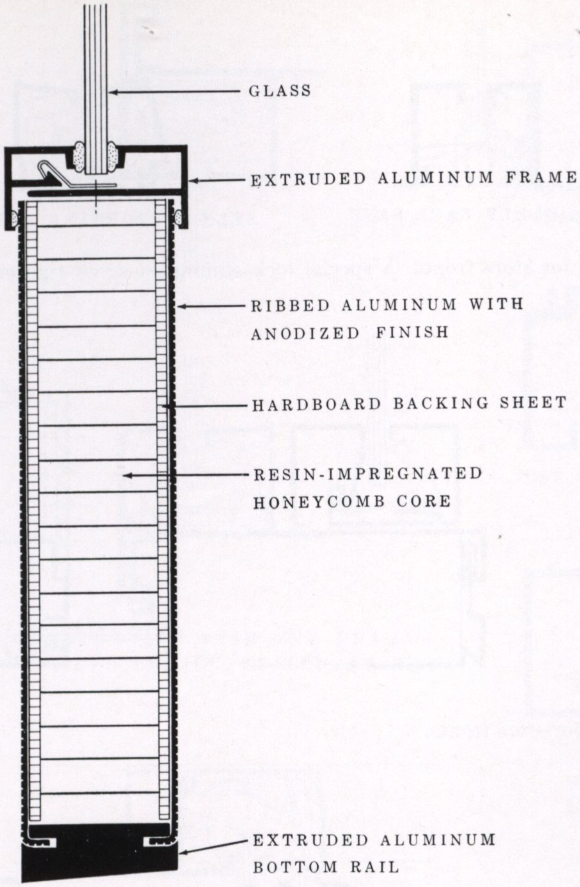


Figure 7-106: Flush door construction.

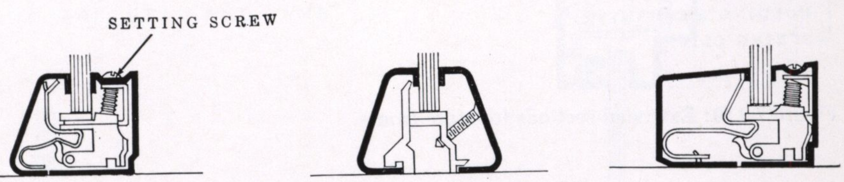


Figure 7-107: Rolled sections for store fronts. Spring clip eliminates all screws on the face of store front and holds the glass firmly without exerting undue pressure on the glass. The controlling screw in the gutter does not work loose by sheet vibration.

were constructed of a metal which does not require painting and does not stain the building face.

The great variety of designs is influenced by the climate, use, architecture and other considerations. Many designs are custom made. The accompanying drawings show some of the devices and products that are available.

SHADE SCREENING: This device is a system of miniature louvres fabricated by stamping an alumi-

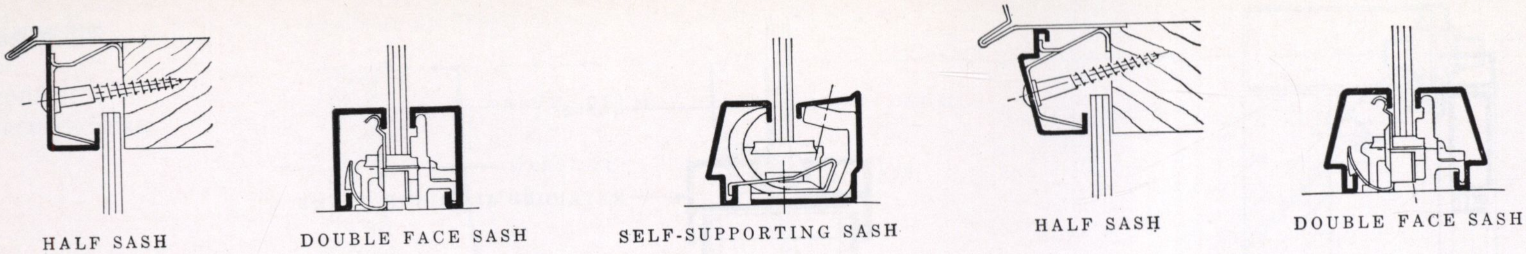


Figure 7-108: Rolled sections for store fronts. A special lock eliminates screw-tightened lugs, while offering a resilient firm setting.

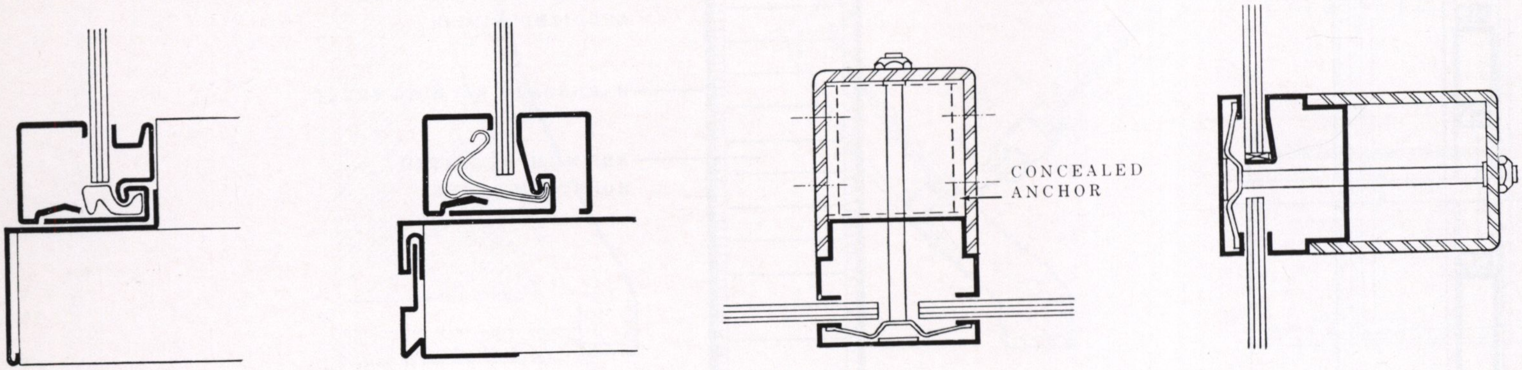


Figure 7-109: Rolled sections for store fronts.

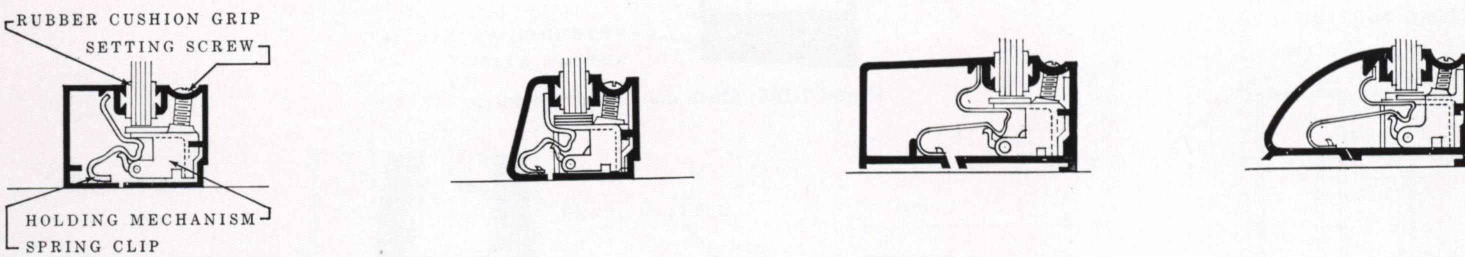


Figure 7-110: Extruded sections for store fronts.

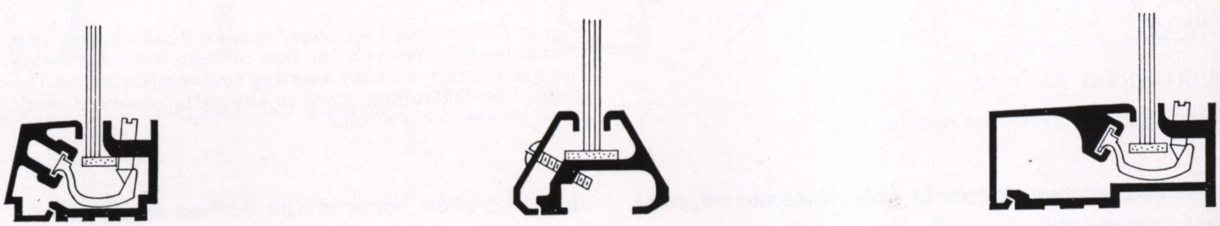


Figure 7-111: Extruded sections for store fronts.

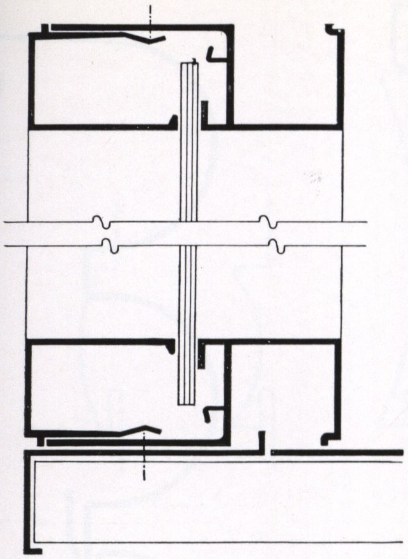


Figure 7-112: Extruded sections for store fronts.

num sheet. (See Figure 7-115.) This screening can be used with most types of windows and is most efficient from the thermal point of view when placed on the exterior. It is also an effective shading device for terraces as it blocks most of the direct sun rays during the hot hours of the day. (See Figure 7-116.)

The screening reduces glare, diffuses the light and reduces solar radiation. It increases privacy because it partially blocks the view from the outside. The closely spaced louvers (17.5 per inch) provide a barrier against all but the smallest flying insects and deflect light rainfall. This screening can be used in wood or metal frames.

VENETIAN BLINDS: The slats of aluminum venetian blinds are usually 2 inches wide and in cross section have a crown for additional stability and rigidity. Available in a variety of finishes and colors.

LOUVERS can run horizontally or vertically, depending on the exposure and architectural solution. On the south side, the louvers running horizontally provide effective shading and can be placed either in a vertical plane or as a sloping sunshade. On the east or west side, vertical louvers, properly placed,

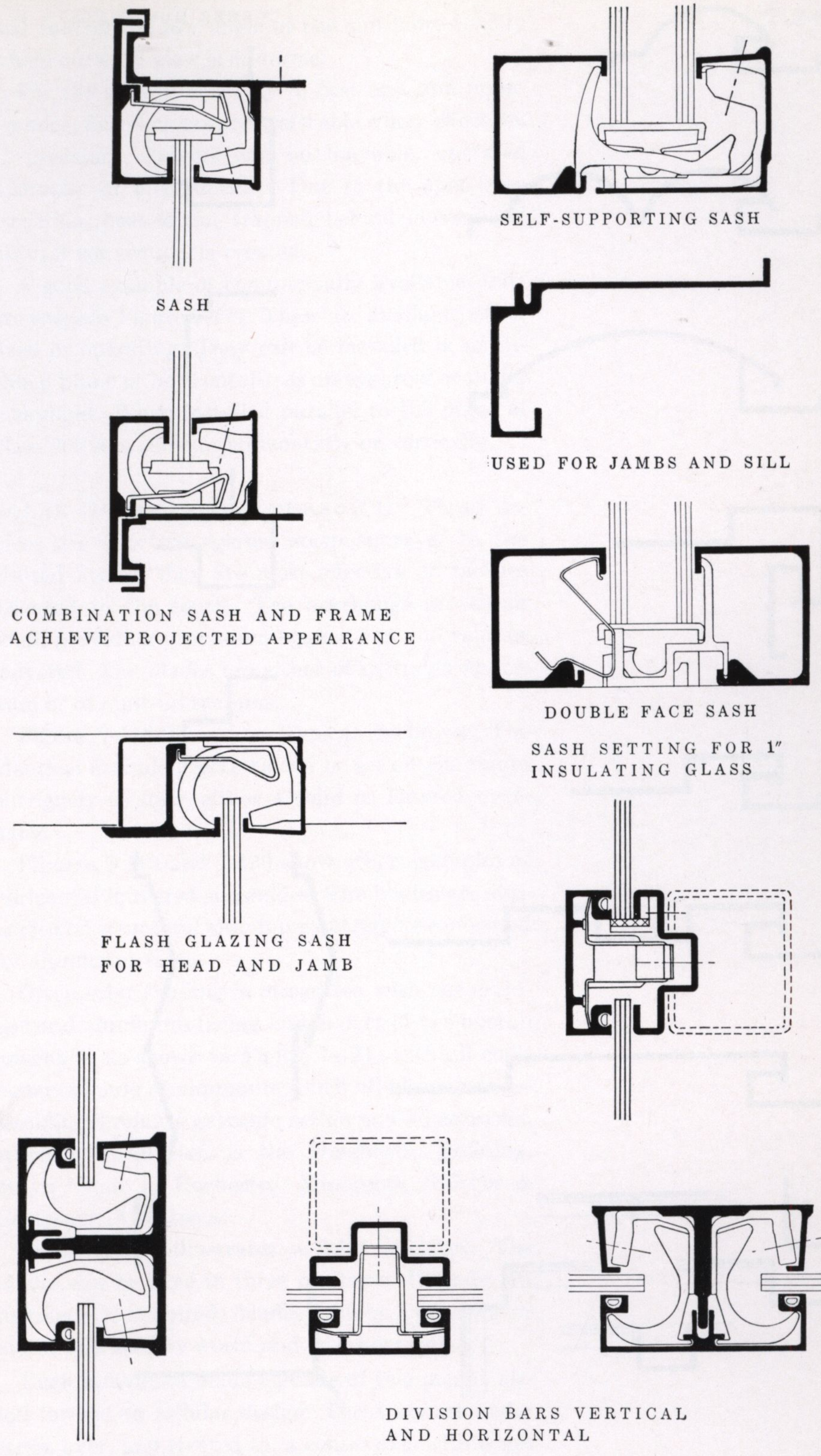
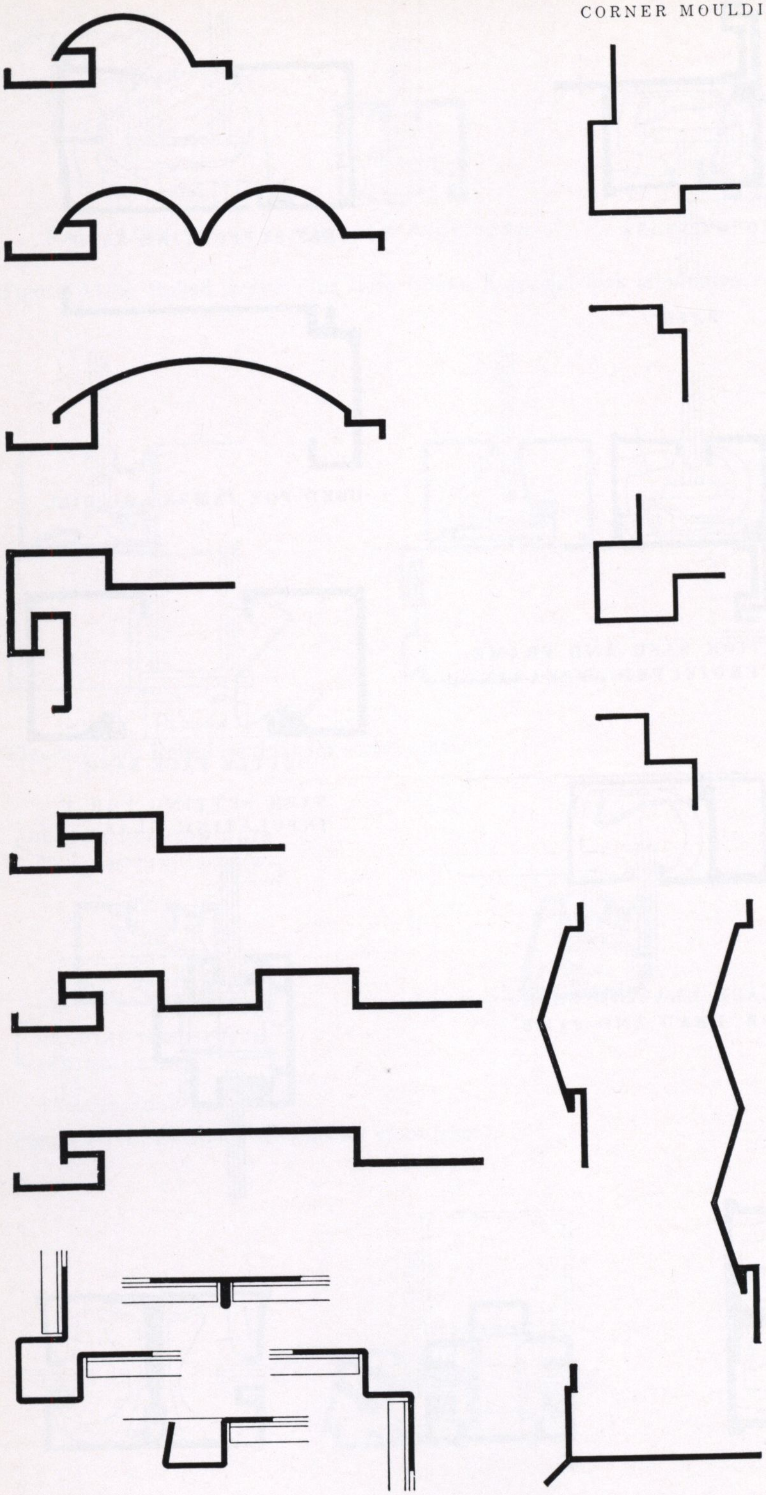
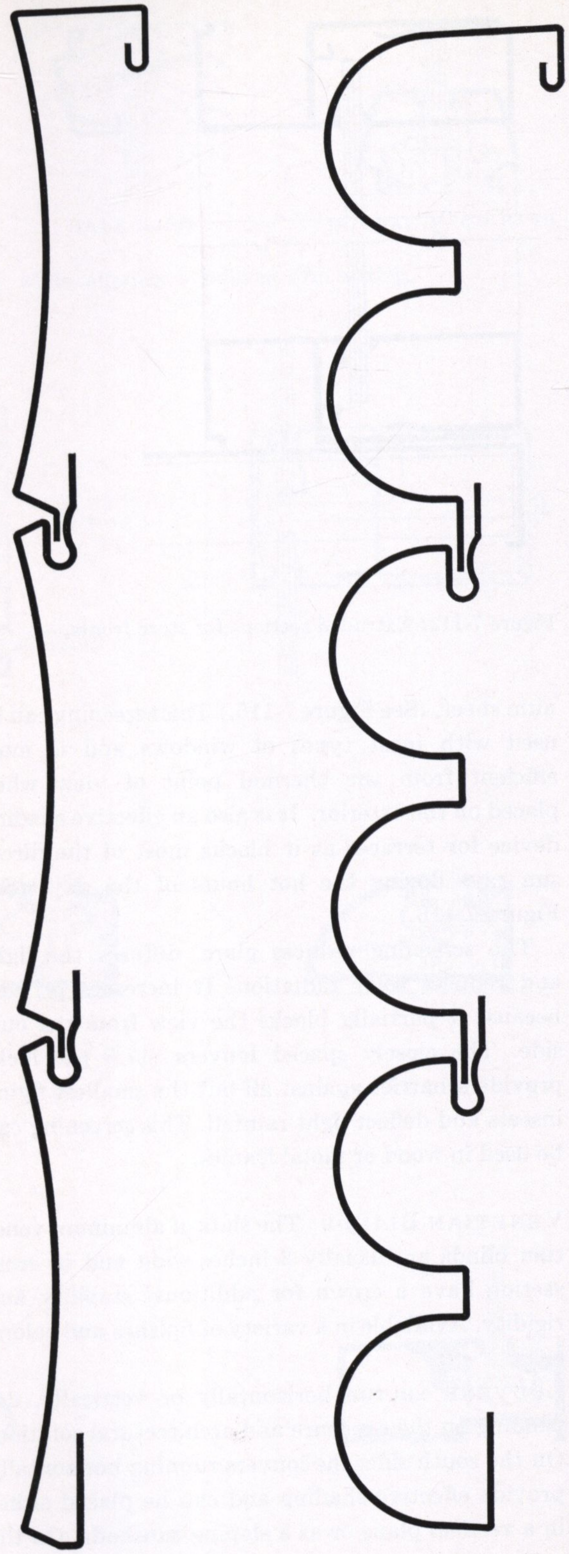


Figure 7-113: Extruded sections for store fronts.

CORNER MOULDINGS





TRIM MOULDINGS

Figure 7-114: Trim moldings for store fronts. Concluded on Page 273.

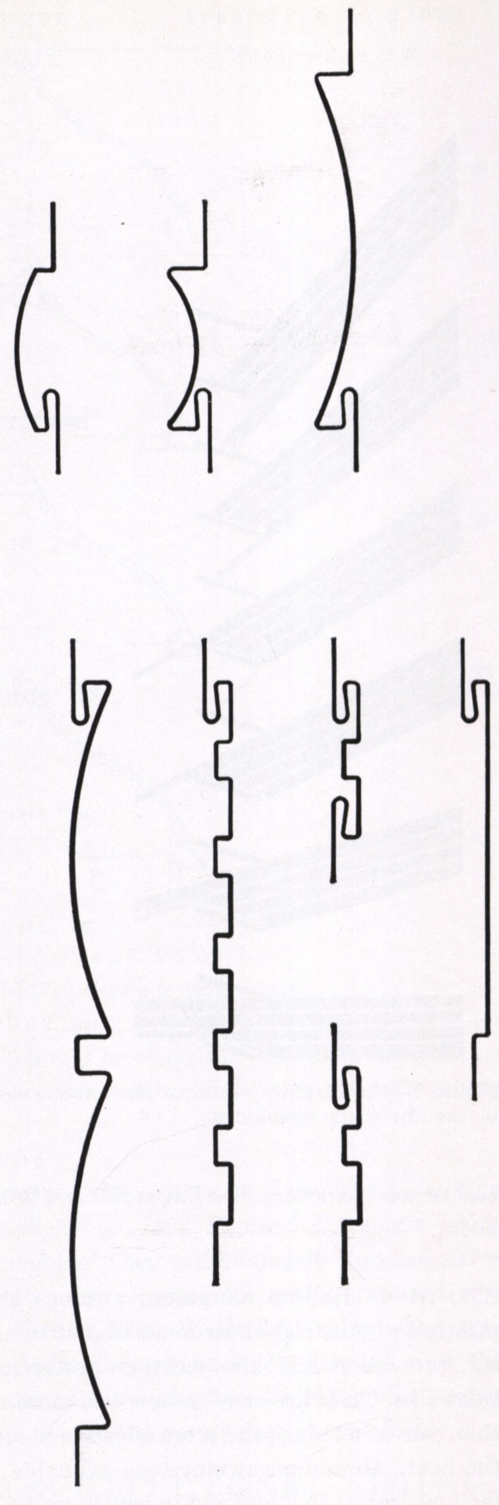


Figure 7-114: Trim moldings for store fronts, concluded.

will control the low angle of the sun more readily where outward view is desirable.

For the sake of economy in first cost and maintenance, fixed louvers are preferable where effective. If necessary, louvers can be movable, operated manually or mechanically. Due to the open construction, heat is not trapped behind louvers and natural convection is created.

A good example of commercially available units are those in Figure 7-117. These are available either fixed or operating. They can be installed in an inclined plane or horizontally as an eyebrow or under a skylight. When installed parallel to the plane of glass, louvers can run horizontally or vertically.

SOLAR OVERHANGS (EYEBROWS): These devices are effective against steep sunrays. In the United States, they are most effective on facades oriented to the south. The overhangs are either solid, providing protection against sun and rain, or louvered. The blades are either of extruded aluminum or of built-up sections.

Figure 7-118 illustrates typical eyebrows. The identical extruded sections can be set on aluminum outriggers to form either a solid or louvred overhang.

Figures 7-119 and 7-120 show other examples of horizontal louvered sunshades. The blades are supported on structural aluminum outriggers connected by aluminum fascia.

Often solar shading is integrated with the architectural aluminum facing and is part of the overall assembly, as shown in Figure 7-121, with all components made of aluminum. Such all-aluminum assemblies eliminate galvanic action and all corrosion staining. Illustrated is the Diagnostic Building, Mayo Clinic in Rochester, Minnesota (Ellerbe & Company, Architects).

Figure 7-122 illustrates a solar eyebrow. The blades can be fixed in three positions. If ready adjustment is required, blades can be manually or motor operated by worm-and-gear operators.

Each individual blade is made of two pieces, airfoil formed to cellular design. These are set under stress over, and riveted to, a center axis with edges joined together by extruded interlocking sections.

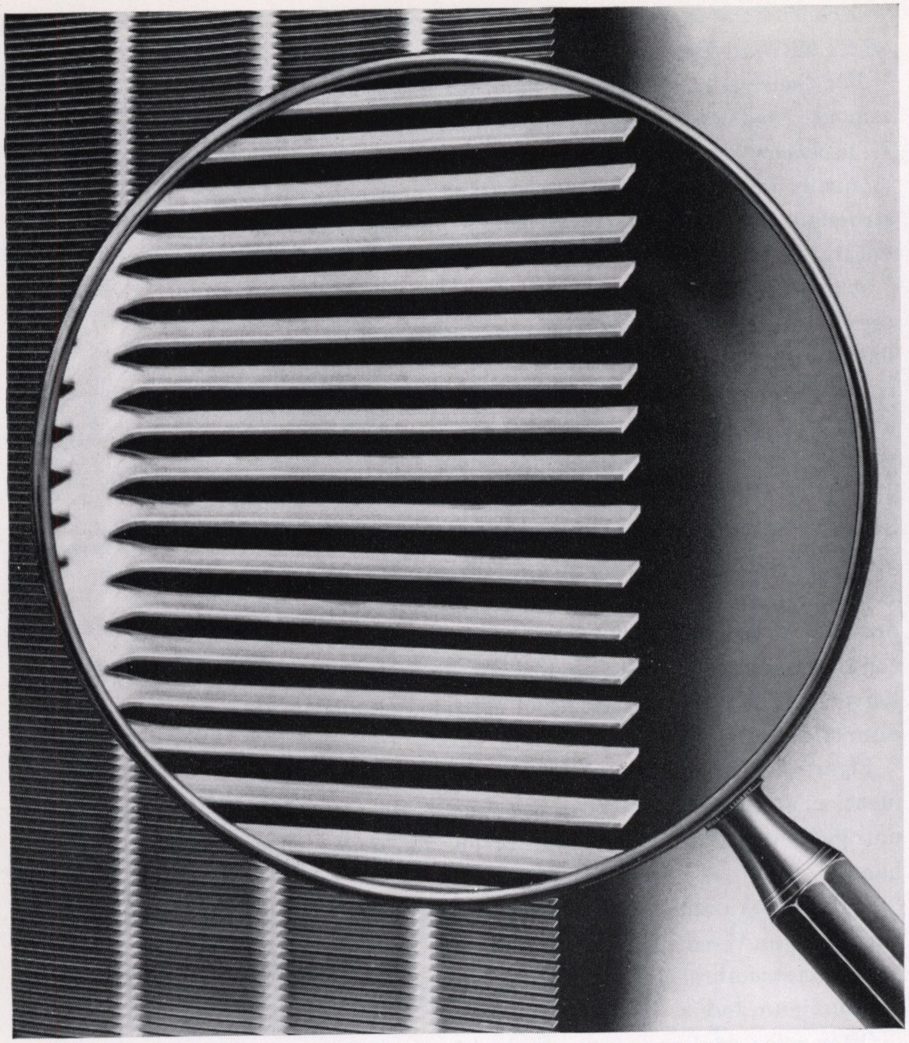


Figure 7-115: Aluminum shade screening.

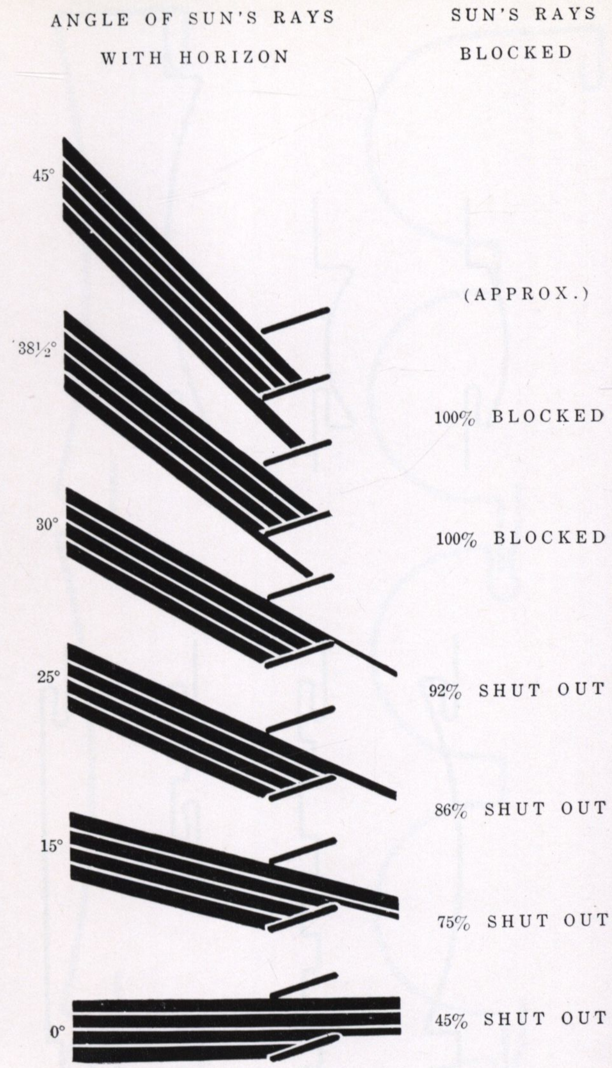


Figure 7-116: Diagram showing the extent of sunrays blocked by shade screenings.

See Figure 7-122 for details. Ends are enclosed with mesh. Maximum length for an individual shade is 8 feet. Where shades are over 8 feet in length, they are made in two or more sections joined together with a concealed expansion clip. Shade frame is also aluminum.

In orientations, where horizontal sun shades are insufficient, a combination of horizontal blades—fixed or adjustable—and vertical fins is used. This system is illustrated in Figure 7-123. Figure 7-124 shows a system, including details of vertical fins, that is effective in the United States in the case of east or west exposure. See Pages 280 and 281 in this book.

AWNINGS: Roll-up aluminum awnings are used mostly in industrial and commercial structures for sun protection and also weather protection over sidewalks. They are easy to operate, more durable than canvas awnings and more effective in reflecting the heat. Aluminum awnings are available in projections from 4 to 8 feet and in widths up to 18 feet. The awning rolls up tight in a concealed box or under a protective hood. (See Figure 7-125.) Opera-

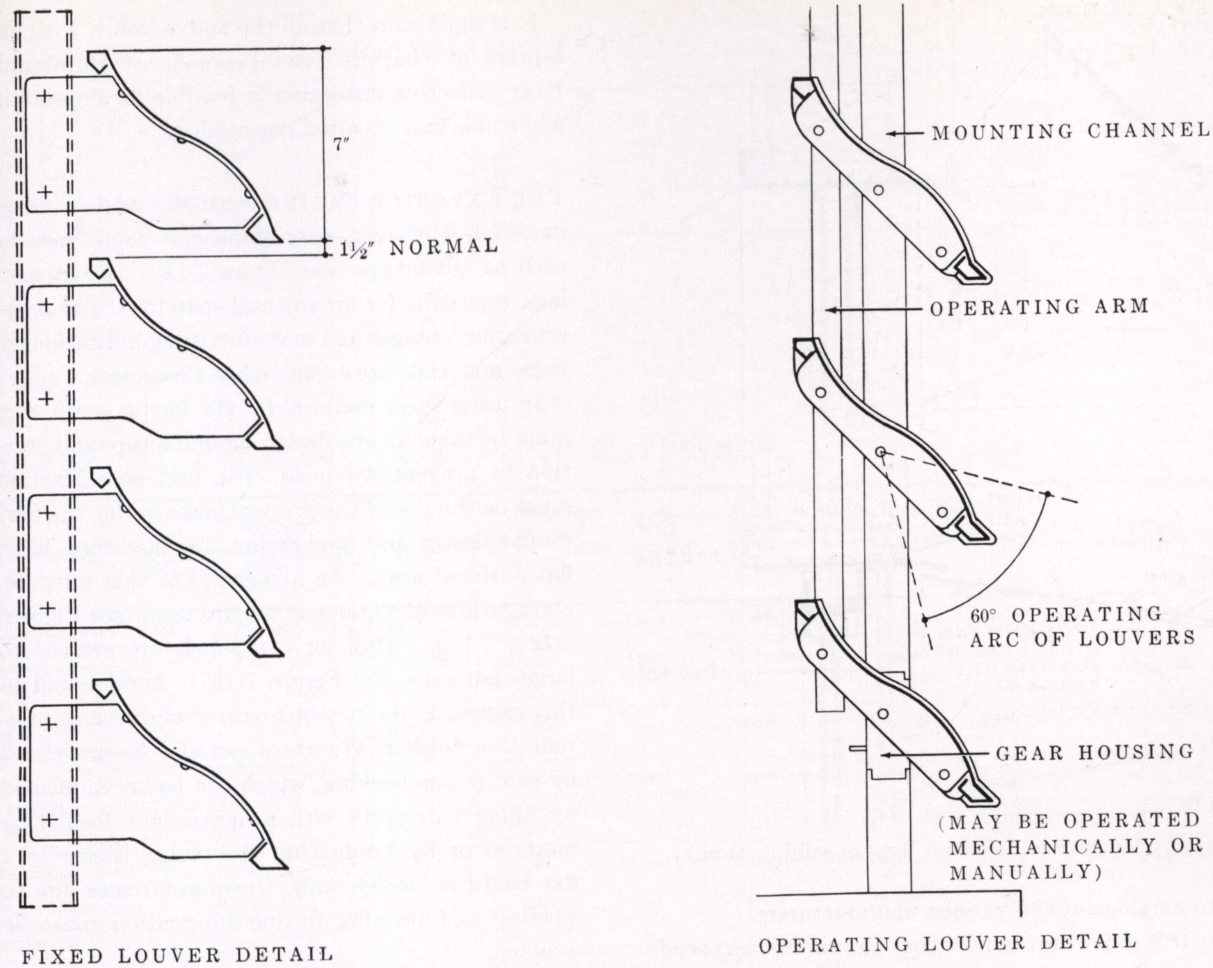


Figure 7-117: Louvers for sun control.

tion is manual or electrical. The slats have a corrosion resistant anodized finish that gives them long life.

Canopies (Marquees) provide protection from sunlight and rain. Figure 7-126 shows ventilated canopies. They can be installed on cantilever supports or are prepared to receive standard pipe hanger fittings. The W-sections, with edges preventing splashing, channel the rainwater to the gutter along the building face while the open spaces between W-sections permit hot air to escape.

7.25 ARCHITECTURAL SIDING AND CURTAIN WALLS

One of the most conspicuous recent advances in building techniques is the rapidly increasing use of thin, light non-load-bearing exterior walls. The use of these curtain walls results in substantial savings, mainly due to the following factors:

—Savings in the structural frame due to decreased wall loads.

—Reduction of heating and air-conditioning loads due to effective insulation.

—Increase in rentable floor area due to thin exterior walls.

—Reduction of construction time due to speedy erection and integration of various elements such as windows, sills, convector and conduit covers, and the like.

The general aspects of curtain wall construction will not be discussed here, and the reader is referred

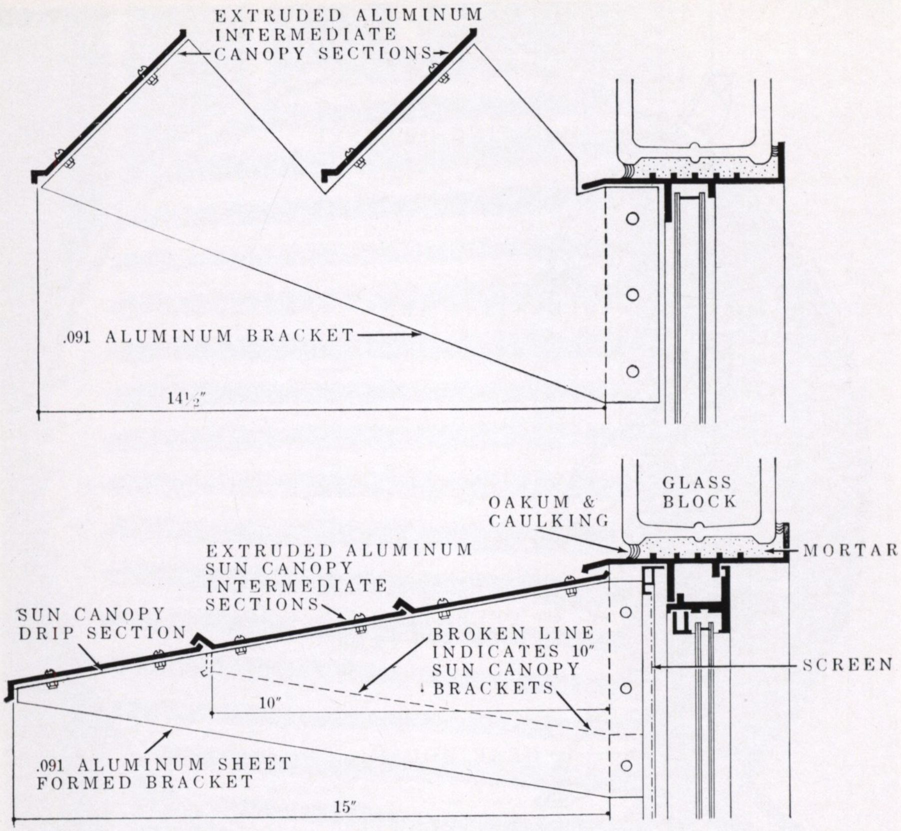


Figure 7-118: Solar overhangs of extruded sections, louvered (top) or solid (bottom).

to catalogs of the various manufacturers.

It is important to note that aluminum has certain natural properties that make its use in curtain wall construction of special advantage. Its light weight allows larger sections to be fabricated and erected. This means fewer joints and economies in erection over panels of other materials. Aluminum's workability, assuring easy forming and fabrication with resulting savings in cost, as well as the great variety in possible finishes and its textures are fully discussed in Chapter 3. Its resistance to weathering is dealt with in detail in Section 2.3. Curtain walls consist of a combination of several or all of the following components:

—Exterior facing.
—Insulation.
—Backup.
—Interior finish.
—Mullions and window assemblies.
—Joints and attachments.

It is significant that all the above items, with exception of "backup" can be made of aluminum. Even reflective insulation is feasible in aluminum, while "backup" is often not needed.

THE EXTERIOR FACING is usually made of sheet material. However, extrusions can sometimes be used to advantage (see Figure 7-138) as can castings, especially for ornamental spandrels. The properties, advantages and manufacturing limitations of these materials are explained in Chapter 3.

In using sheet material for the facing, great care must be taken in the design, manufacture and erection to prevent waviness. The first consideration must be the use of the proper thickness for the particular design and application. Furthermore, large flat surfaces are to be avoided. For this purpose, corrugations of various kinds are used (see Figures 7-127, 7-129, 7-130), or the panels are pressed to larger patterns (see Figure 7-137). Another aid in this respect is the use of textured sheets and nonreflective finishes. Waviness can also be prevented by continuous backing, which can be accomplished by filling pan units with a lightweight insulating material or by laminating the facing sheets to a flat board or honeycomb. Unequal stresses due to welding and forming during fabrication must be avoided.

Provisions must also be made to allow for expansion and contraction from temperature changes. Finally, it is essential that erection and attachments avoid racking or warping of the panels by providing adjustable devices that allow for movement of the structure. (See Figures 7-132, 7-133, 7-134, 7-135.)

INSULATION AND CORE MATERIALS are available in a wide range. Some consist of noncombustible sheets or batts while others can be poured in place or sprayed on. Table 7-12, reproduced from a study prepared by the School of Architecture, Princeton University, on "Curtain Walls of Stainless Steel," gives a comparison of core and insulating materials.

To ensure the life and effectiveness of insulation, a vapor barrier is essential, as are provisions for the escape of condensation through weepholes or evap-

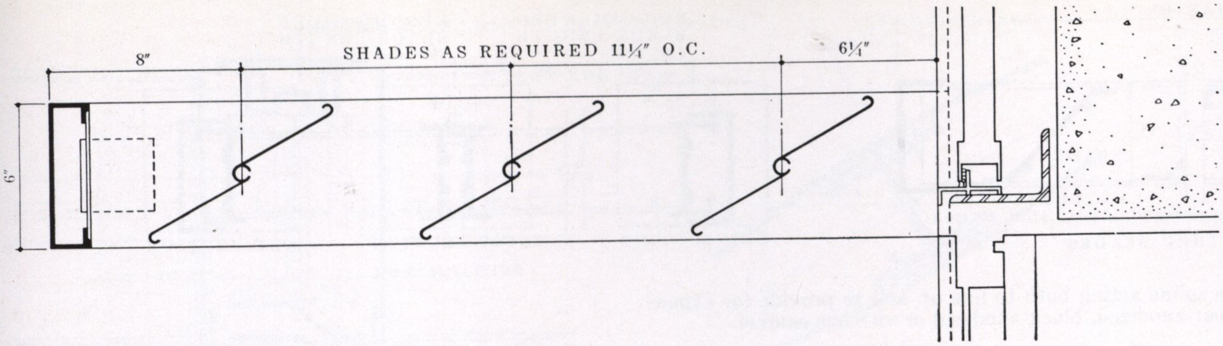


Figure 7-119: Solar shade.

TABLE 7-12: CORE AND INSULATING MATERIALS

MATERIAL	WEIGHT[1] POUNDS	AVAILABLE THICKNESS INCH	AVAILABLE SIZES	CONDUCTIVITY BTU PER INCH	MOISTURE RESISTANCE	FIRE RESISTANCE	THERMAL EXPANSION	COST[1]	REMARKS
Gypsum board	5.23	½ to 2	4′ x 8′, 10′, 12′	1.41	Poor	Incombustible		12¢	
Asbestos-cement with fiberboard core	3.75	1⁹⁄₃₂ to 2	4′ x 6′, 8′, 9′, 10′, 12′	.40	Fair (expands)	Incombustible	Negligible	40¢	
Marinite (calcium silicate)	3.00	½ to 2	4′ x 8′, 10′, 12′	.75	Poor	Excellent	Negligible	High	
Cemented excelsior	2.3	2 to 3	32″ wide	.45	Fair (expands)	Incombustible	Negligible	2″ thick—12.5¢ 3″ thick—11.0¢	
Foamglas	.75	2 to 5	12″ x 18″	.39	Excellent	Incombustible	Negligible	13¢	Vapor proof
Paper honeycomb with perlite fill	.7			.39	Fair	Poor	Negligible	16¢	
Cork board	.6	1 to 6	12″ x 36″ to 36″ by 36″	.26	Fair	Fire retardant	Negligible		
Fiberglas P-F 615	.47	1 to 4	24″ x 48″	.24	Good	Incombustible	Negligible	6.5¢	Batts resist fire to 450° Fibers resist fire to 1000°
Aluminum honeycomb	.4				Excellent	Incombustible	High	80¢	
Paper honeycomb	.3	to 4		.58	Fair	Poor	Negligible	12¢	
Mineral wool	.25			.27	Fair	Excellent	Negligible	2¢	
Polystyrene foam	.16			.27	Fair	Self-extinguishing	Negligible		
Pumice concrete	8.0			2.42	Poor	Excellent	Small		
Perlite concrete	2.6			.77	Poor	Excellent	Small		1 to 5 mix. Shrinks considerably in curing
Foam concrete	2.5			.6	Good	Excellent	Small	10¢	Including material & labor
Vermiculite Concrete	2.25			.76	Poor	Excellent	Small		1 to 6 mix. Shrinks considerably in curing
Sprayed Asbestos	.9	½ to 2		.26	Good	Excellent			

[1] Per square foot 1″ thick; costs are approximate.

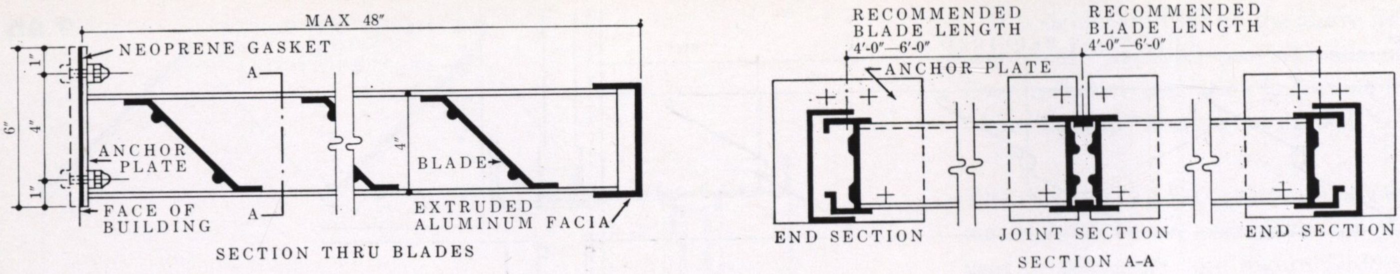


Figure 7-120: Solar shade. Note spline acting both to line up and to provide for expansion. Available in mill finish, clear anodized, black anodized or vitreous enamel.

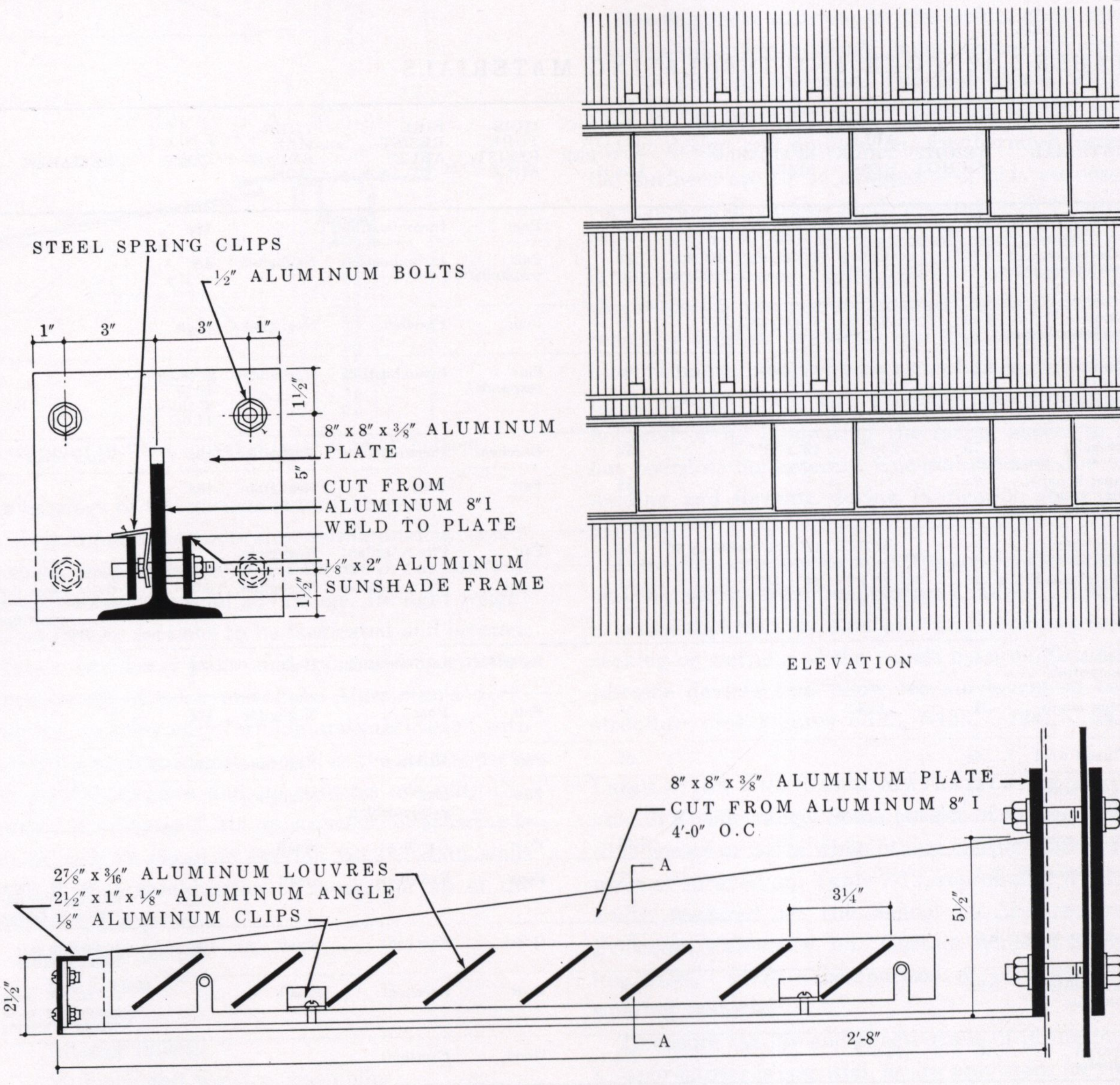
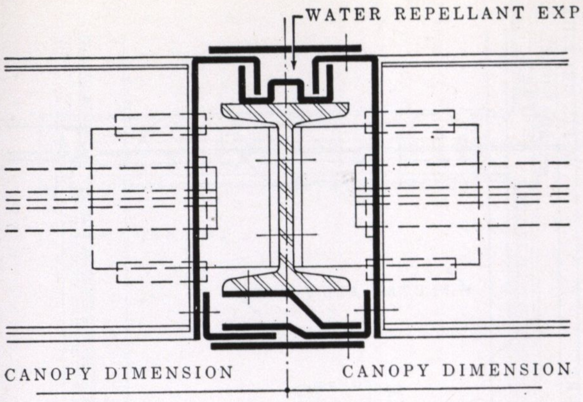
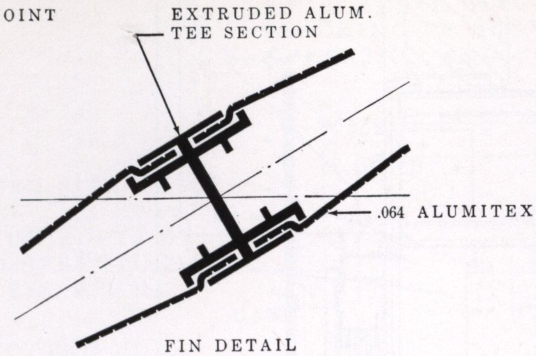


Figure 7-121: Elevation and details of louvered solar shade.



SECTION THROUGH LOOKOUT



FIN DETAIL

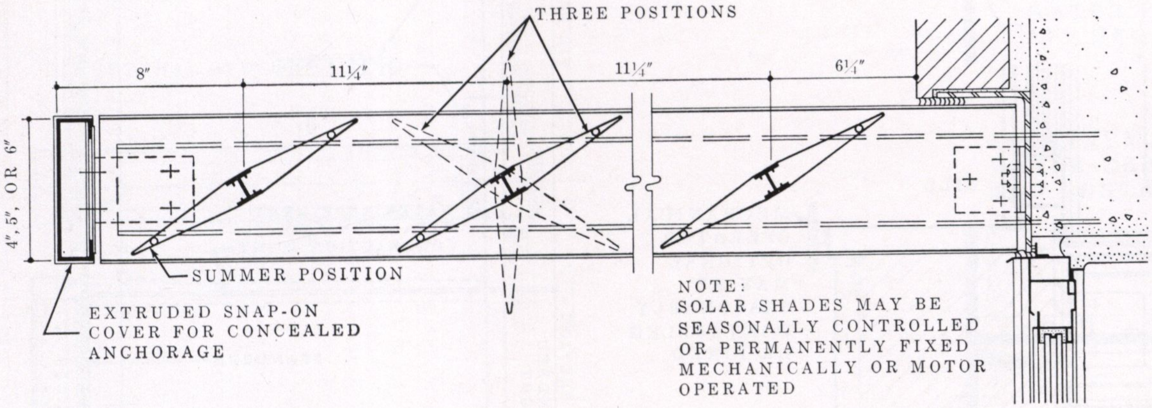


Figure 7-122: Solar eyebrow with built-up blades—fixed or adjustable.

oration through a ventilated air space.

BACKUP has the following functions:

—Insulation
—Base for applying finish
—Fireproofing

The first two functions can be taken care of effectively and economically by a curtain wall panel without backup. In most cases, the use of backup is dictated by the requirements of fireproofing.

Requirements of many new city codes can be met by the use of noncombustible core materials having a fire resistance of 1 or 2 hours. Some other codes, virtually dictating a masonry backup, are inconsistent in permitting fully glazed curtain walls while prohibiting the substitution of glazing by panels of a 1 or 2-hour rating.

INTERIOR FINISH is ideally an integral part of the wall panel. It can be laminated to the core or attached in some other way as a prefabricated component, or it can be applied in the field. The finish

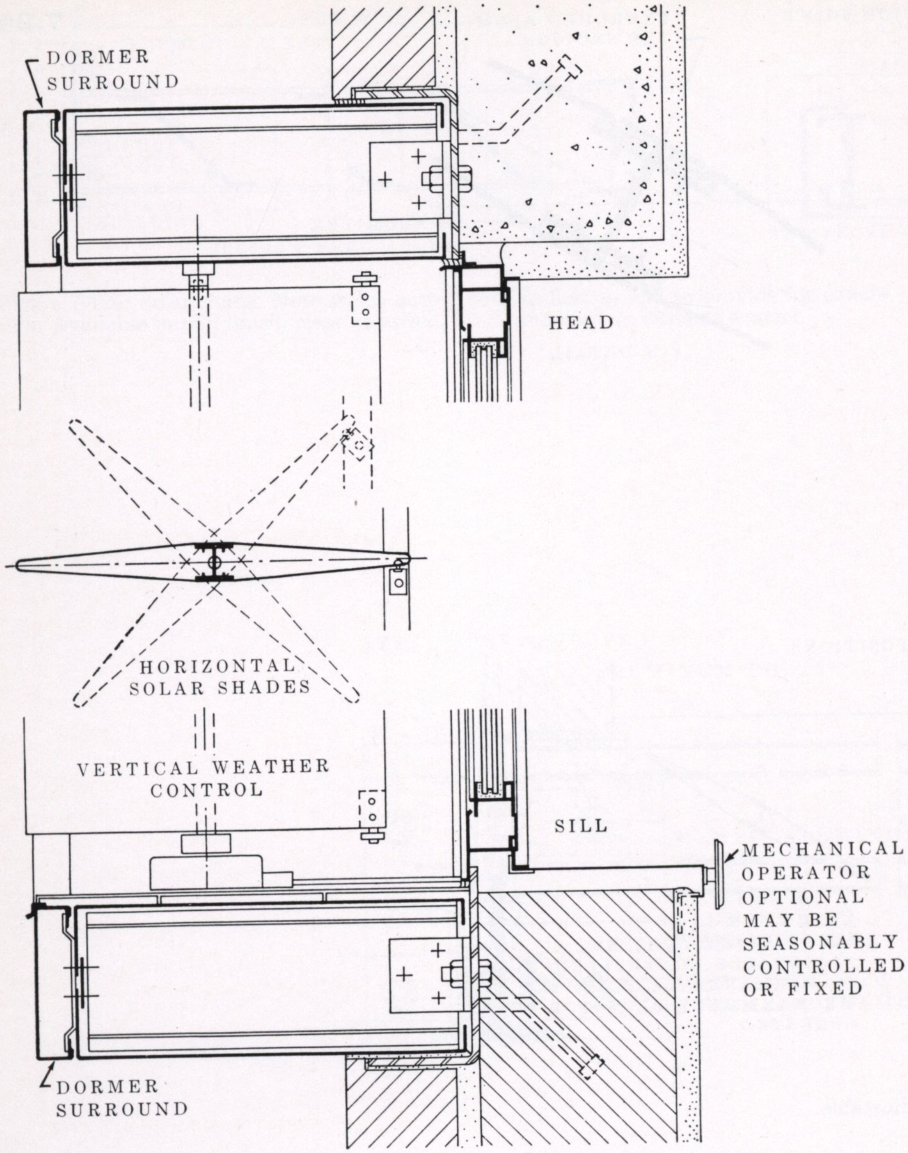


Figure 7-123: Combination of vertical fin with horizontal blades.

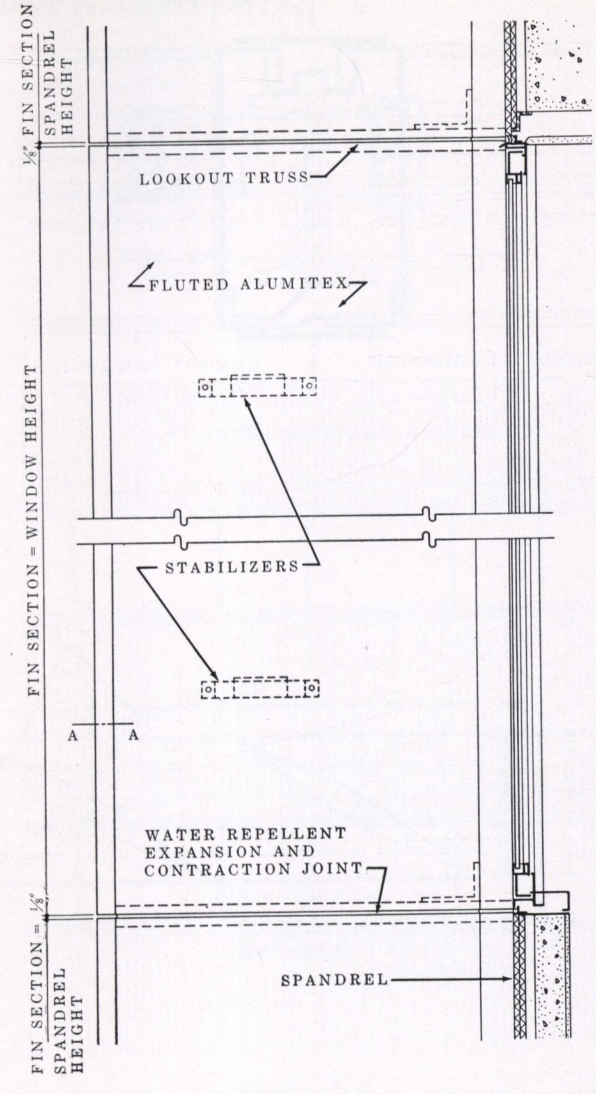
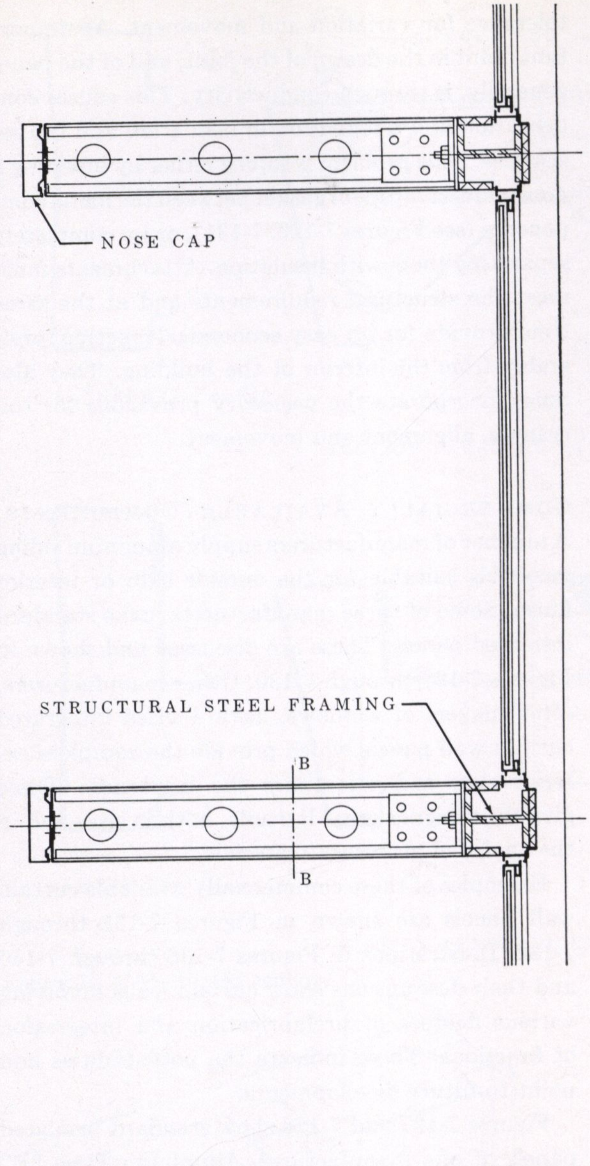


Figure 7-124: Vertical solar fin elevation. For plan and section details, see Page 281.

can be of aluminum (see Figures 7-131, 7-138) or other material. In some instances, continuous convector or conduit covers constitute the entire interior finish (see Figures 7-135, 7-137). Where backup is used, the finish can be applied in the conventional way.

Architectural siding and panels that do not span from floor to floor or between architecturally treated mullions are attached to girts. In some buildings it is possible to leave them exposed, in others a separate finish facing has to be applied. Figure 7-130 shows an integrated system of exterior siding and interior insulating finish.

MULLIONS AND WINDOW ASSEMBLIES are the components of most commercially available



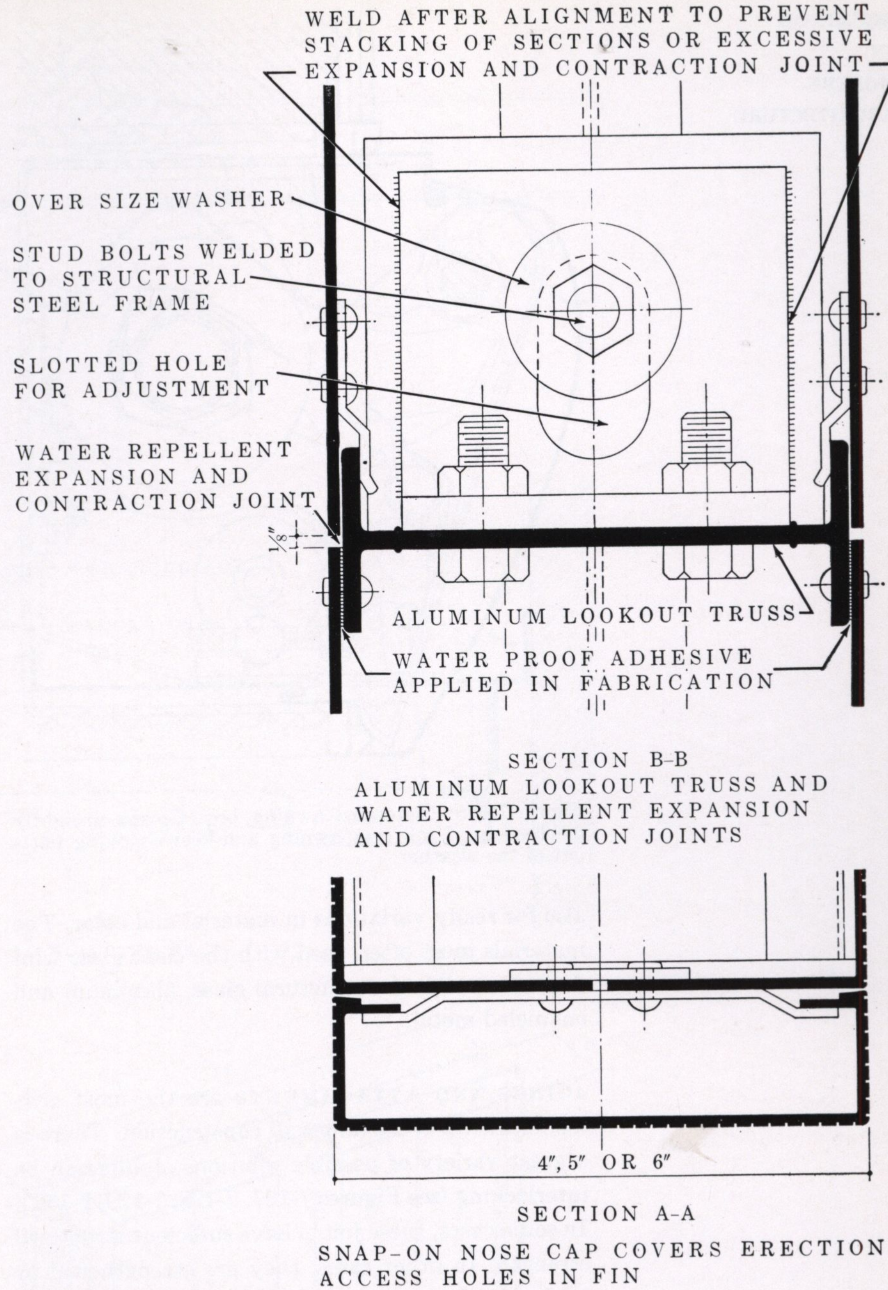


Figure 7-124: Vertical solar fin, plan and section details. See elevation on Page 280.

curtain-wall grid systems. The mullions, often structural, are extended window mullions which receive the windows and opaque components of the wall. Most of them have provisions for attaching panels and weather seal. At the same time they permit the necessary movement. The mullions are usually built up of extrusions (see Figures 7-132, 7-133, 7-134).

In some mullion type curtain walls, structural vertical and horizontal steel members are faced with aluminum (see Figure 7-139), or special extruded structural aluminum members form a grid for a fully glazed assembly (see Figure 7-140). The mullion type curtain wall has produced the most satisfactory architectural solutions. It seems to express well its idea, and the grid provides the proper scale and setting for the other elements. It provides

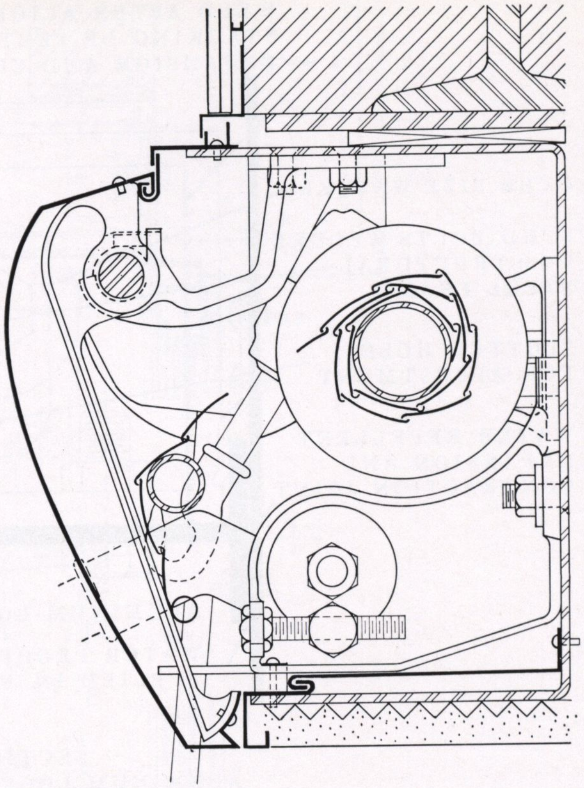


Figure 7-125: Concealed awning box. Covers unsightly mechanism of roll type awning and keeps moving parts out of the weather.

also for ready variations in material and color. The materials most often used with the clear glass window assemblies are structural glass, aluminum and enameled metal.

JOINTS AND ATTACHMENTS are the most critical elements of curtain wall construction. There is a great variety of possible solutions. Joints can be interlocking (see Figures 7-127, 7-128, 7-129, 7-138). In some cases, these joints have sufficient structural strength. In other cases, they are strengthened or backed with structural mullions (see Figures 7-136, 7-137).

Certain types of joints are self-draining or are made weathertight by rubber gaskets or by caulking (the least desirable method). Some joints have splines or batten type covers, and frequently the joints are taken care of by the mullions, as discussed above.

The joints have to provide a sufficient amount of tolerance for variation and movement. An important point in the design of the joint, and of the panel generally, is through-conductivity. This causes condensation and a reduction in insulation and fire resistance. This problem is solved either by inserting a nonconductive tape or gasket between the metal components (see Figures 7-128, 7-131), or by completely separating them with insulation. Attachments must meet the structural requirements and at the same time provide for an easy economical erection, preferably from the interior of the building. They also must incorporate the necessary provisions for tolerances, alignment and movement.

COMMERCIALLY AVAILABLE COMPONENTS: A number of manufacturers supply aluminum siding materials suitable for the outside skin or interior finish. Some of these manufacturers make standard insulated panels. These are discussed and shown in Figures 7-127 through 7-130. Other manufacturers, often makers of windows, have devised integrated curtain wall panels which provide the complete exterior skin and sometimes the insulation. These give the designer great latitude, both in sizes and in the choice of accessory materials.

Examples of these commercially available curtain wall panels are shown in Figures 7-131 through 7-135. Illustrations in Figures 7-136 through 7-140 and their descriptions show curtain walls involving various degrees of prefabrication and integration of functions. These indicate the potentialities and point to future developments.

Figures 7-127 and 7-128 show standard insulated panels of one manufacturer. Aluminum Type "F" Panels shown in Figure 7-127 are formed from a 16 B & S gauge sheet with mill finish of an alloy which offers high structural strength and excellent resistance to weathering and corrosion.

Factory-assembled "F" panels are formed from two rolled sections, a flat interior sheet and a fluted exterior sheet. Both have formed male and female side joints for easy interlocking during erection and to ensure uniform coverage. The exterior sheets are fastened to 1½-inch depth spacer channels, spaced 4 feet o.c. throughout the length of the panel section for the combined effect of shear transfer and to

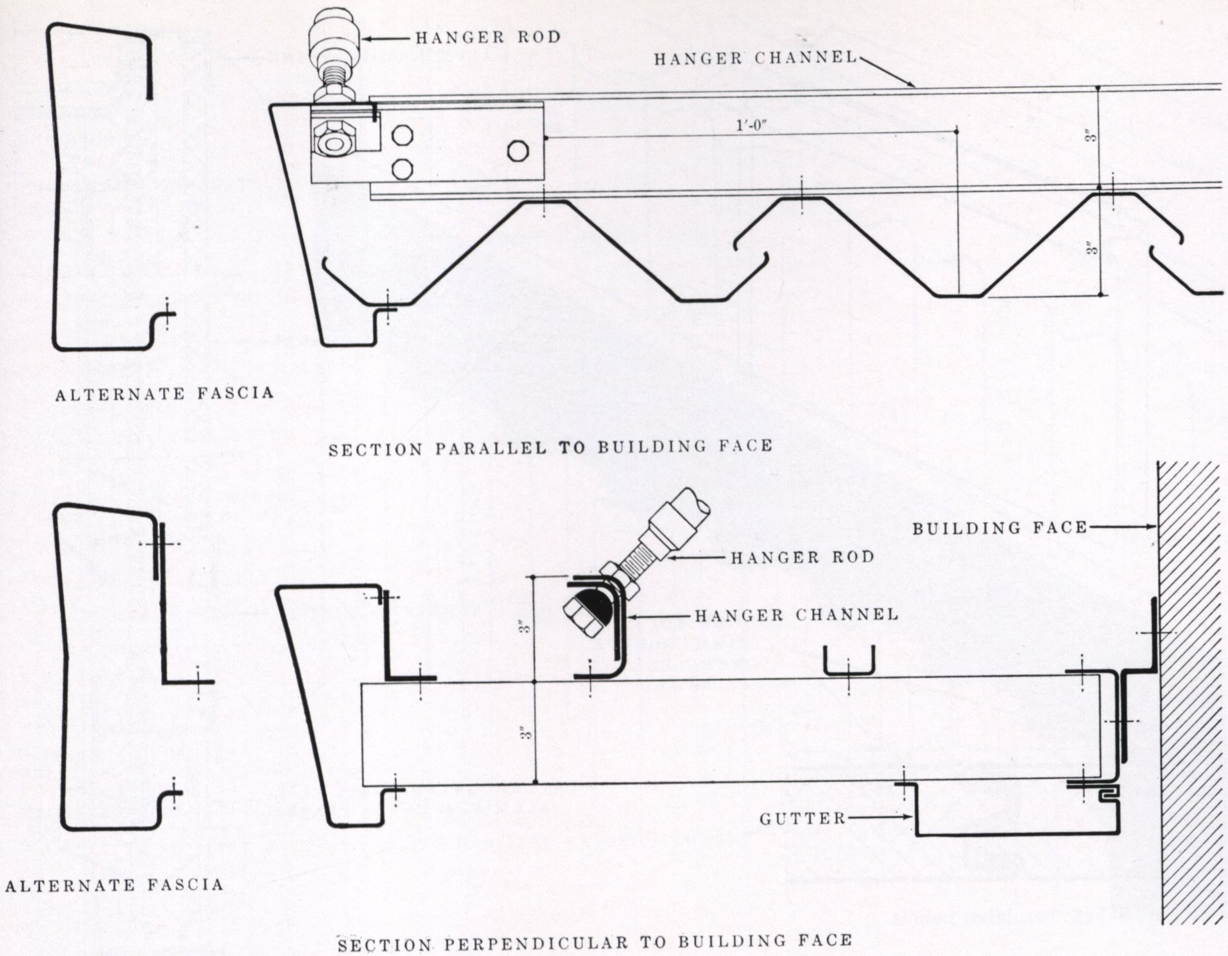


Figure 7-126 Ventilated canopy.

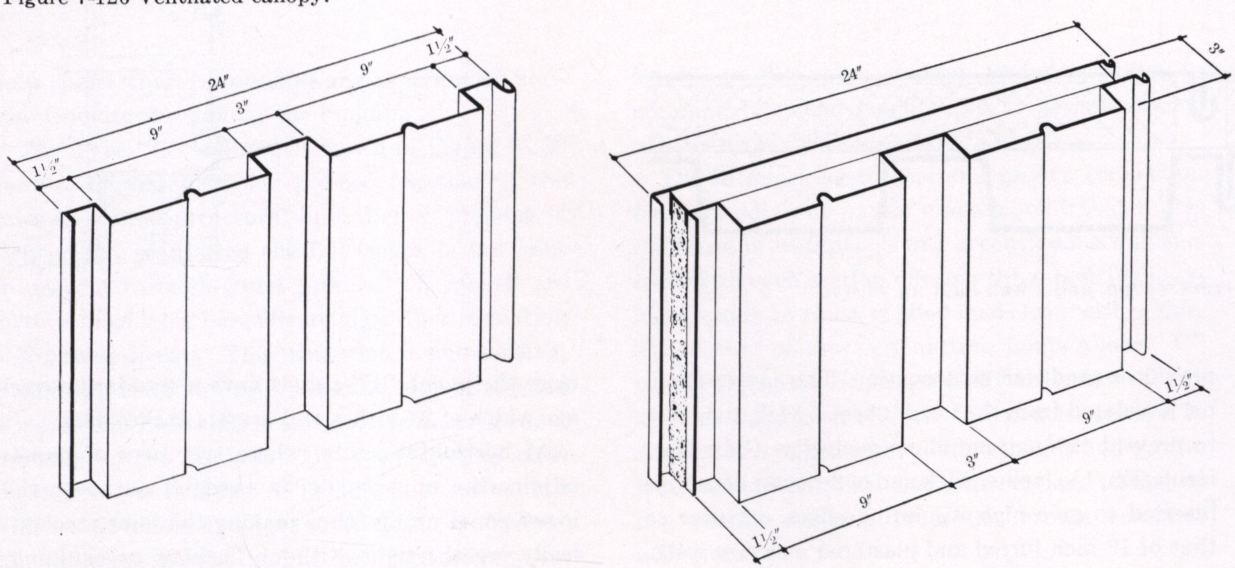


Figure 7-127: Insulated panels.

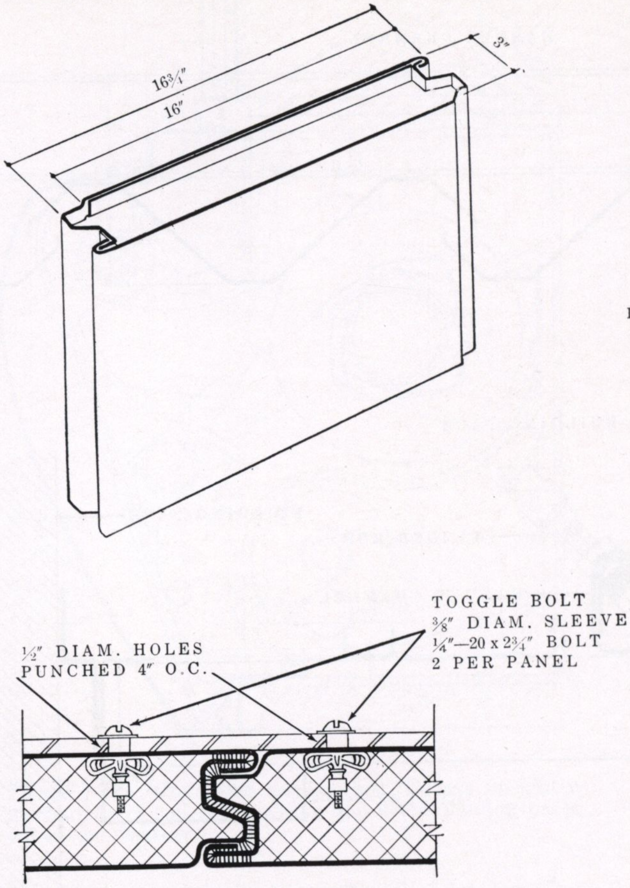
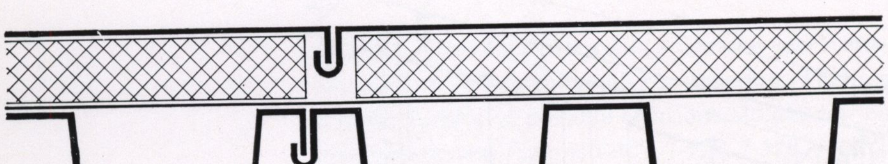


Figure 7-128: Insulated panels.



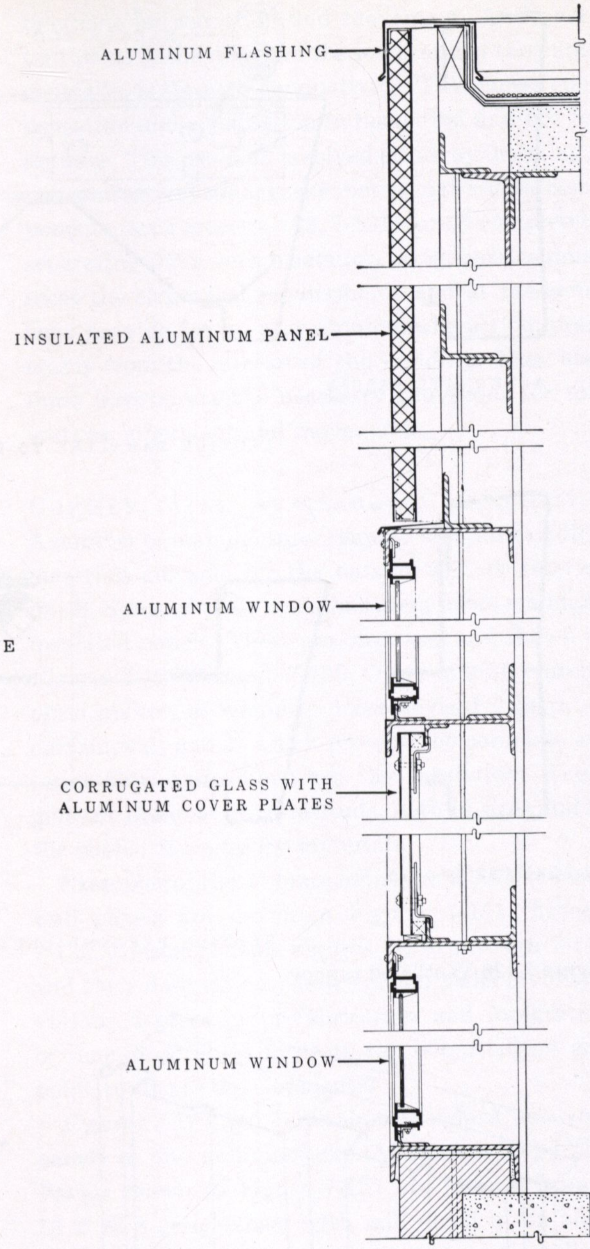


Figure 7-129: The Q-panel in cross section, and a wall built up with it.

provide a sandwich construction. The spacer channel is isolated from the inside sheet by felt stripping to prevent through-metal conductivity. Glass fiber insulation, 1½ inches thick and of 2-pound density is inserted to give high insulating effect, superior to that of 12-inch furred and plastered masonry walls. Die-cut end closures and profile plates completely close the panel. "F" panels have a standard coverage width of 24 inches and are 3¼ inches deep.

At horizontal joints, where two tiers of panels adjoin, the upper panel is swedged out over the lower panel profile, thus making the joint mechanically weathertight without flashing or caulking. Panels are rolled to lengths to accommodate contin-

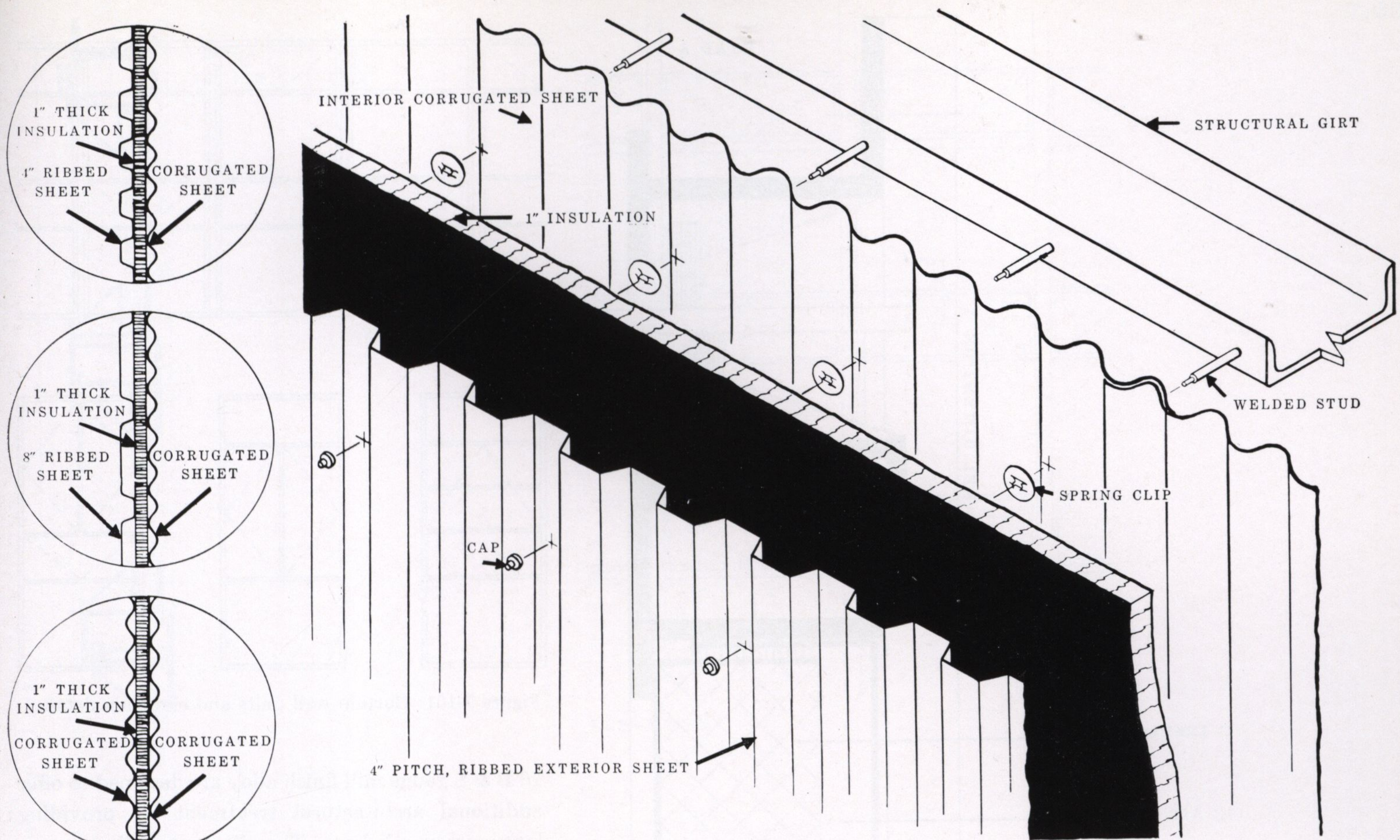


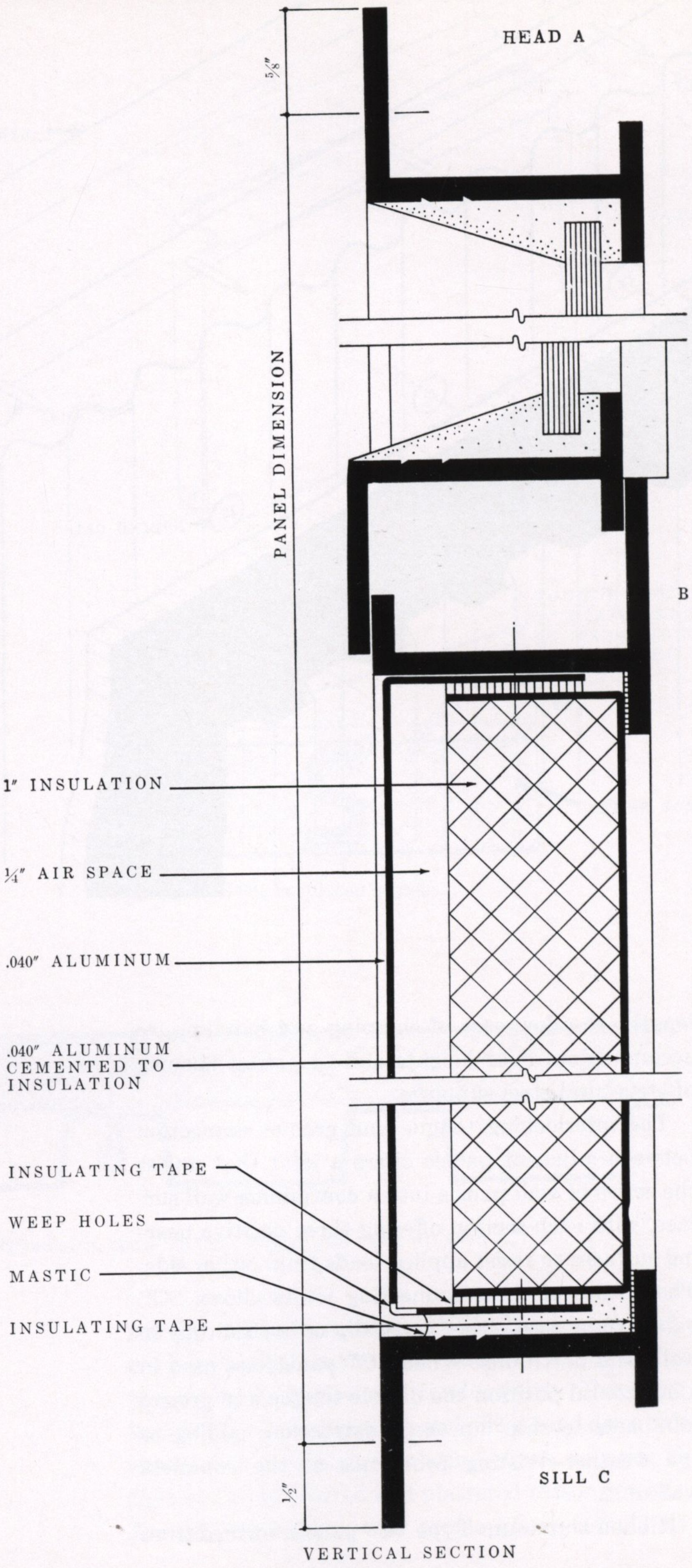
Figure 7-130: Reyconowall insulated wall system.

uous spans wherever possible and to minimize horizontal joints throughout the building.

The Type "C" wall panel shown in Figure 7-128 consists of two members pressed together at the sides to form a structural unit. Before pressing, a strip of felt is inserted the full length of the joint to prevent through-metal contact. The panels are factory filled with borosilicate glass fiber insulation of 2-pound density. This insulation is non-settling, chemically inert and acid resistant. An end closure is inserted at both ends of the panel to ensure proper retention of the insulation and to completely close the building unit. Type "C" panels have a standard width of 16 inches and a standard depth of 3 inches. The ordinary lengths used in construction vary between 6 feet and 14 feet (the maximum available length) to allow ease of shipping and handling, to accommodate floor heights and to permit spacing of structural steel supports.

The interlocking tongue and groove connection between adjacent panels offers a joint that unites the series of wall panels into a continuous wall surface, with each section offering three positive bearing surfaces to resist applied loads from either side. The nature of these connecting joints allows "C" panels to be used either vertically or horizontally in walls and partitions. When "C" panels are used in a horizontal position the double tongue and groove joint acts to ship lap the construction, adding to the weather-resisting properties of the complete wall unit.

Ribbed aluminum Type "C" panels, formed from



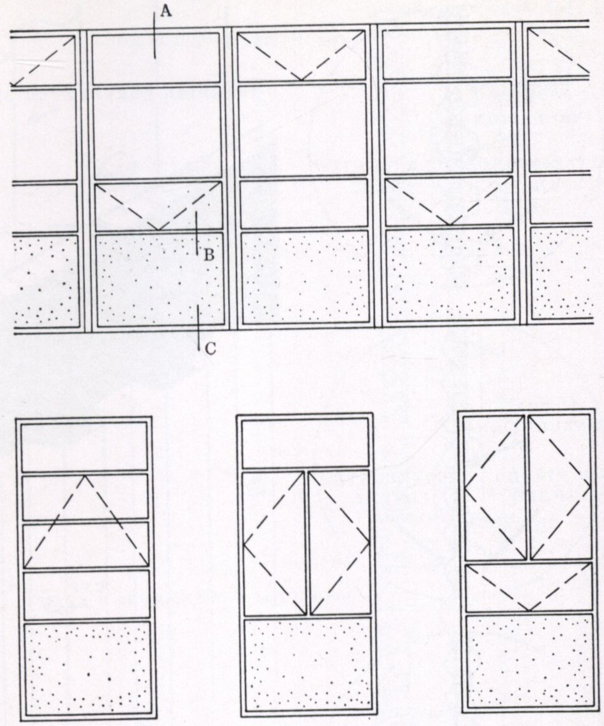
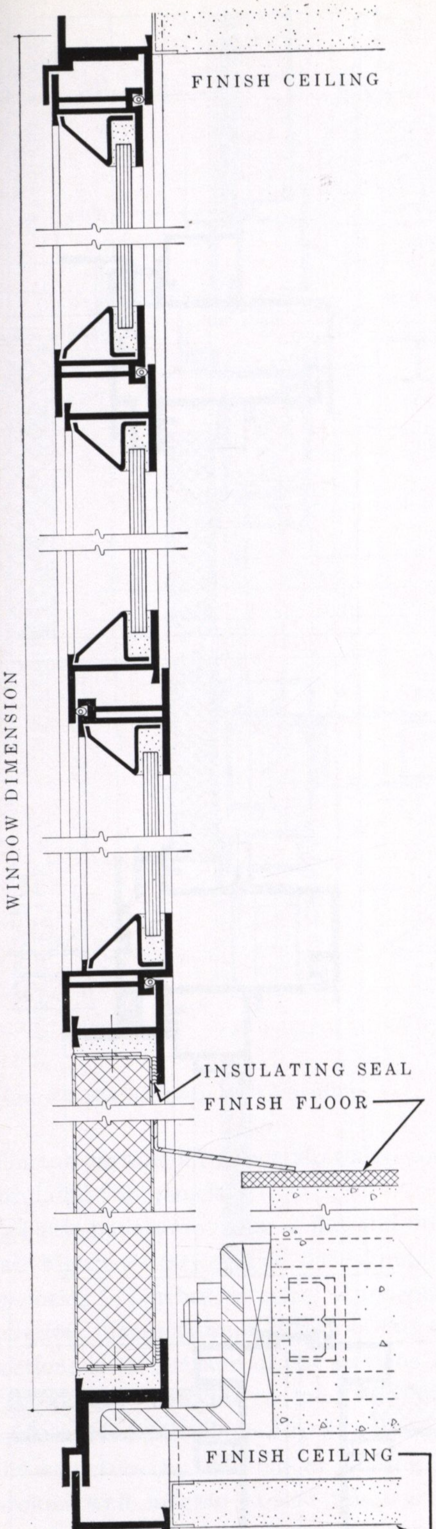


Figure 7-131: Curtain wall units and elevation detail.

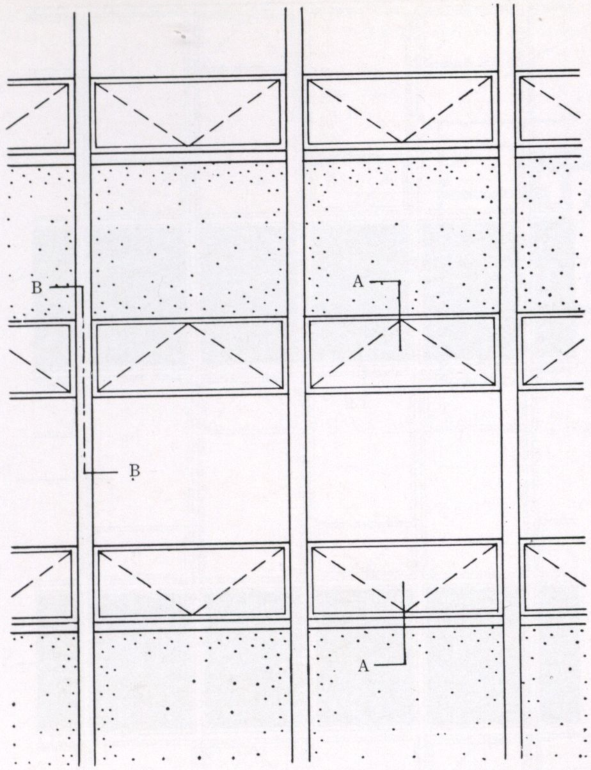
16 B & S gauge mill finish alloy are designed to offer additional architectural treatment by providing long narrow rib lines. The ribs are shallow, semicircular, inturned flutes of approximately $\frac{3}{8}$-inch opening, $\frac{3}{16}$-inch deep. Four ribs are spaced evenly across the face of the panel and so formed that when a wall elevation is viewed in its entirety, the ribbed lines and the lines of the side lap blend together. In addition to providing architectural treatment, the metal panels are stiffened against compression and wind loads by the ribs.

Figure 7-129 shows the use of the "Q" panel. This industrial building (designed by Raymond & Rado for the Electrolux Corp. in Old Greenwich, Conn.) illustrates the combination of various elements that best meet the requirements in the particular areas. Above the bottom section of the wall, built of masonry for resistance to impact, there is a continuous glass area composed of a top and bottom strip of aluminum ventilating sash and an 8-foot middle strip of glare-reducing fixed corrugated glass with aluminum cover plates at the vertical joints.

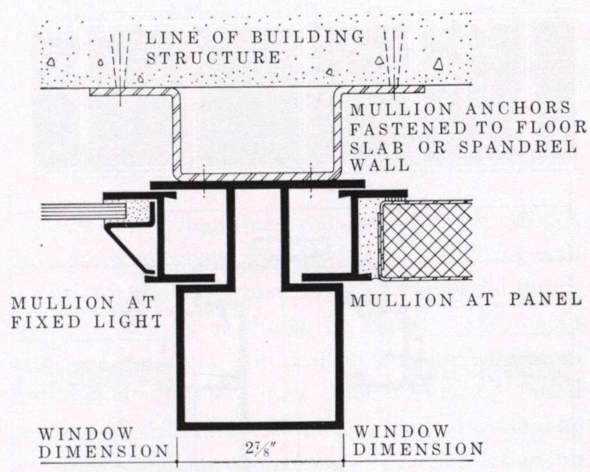


SECTION A–A

FLOATING TYPE VERTICAL MOVEMENT PROVISION



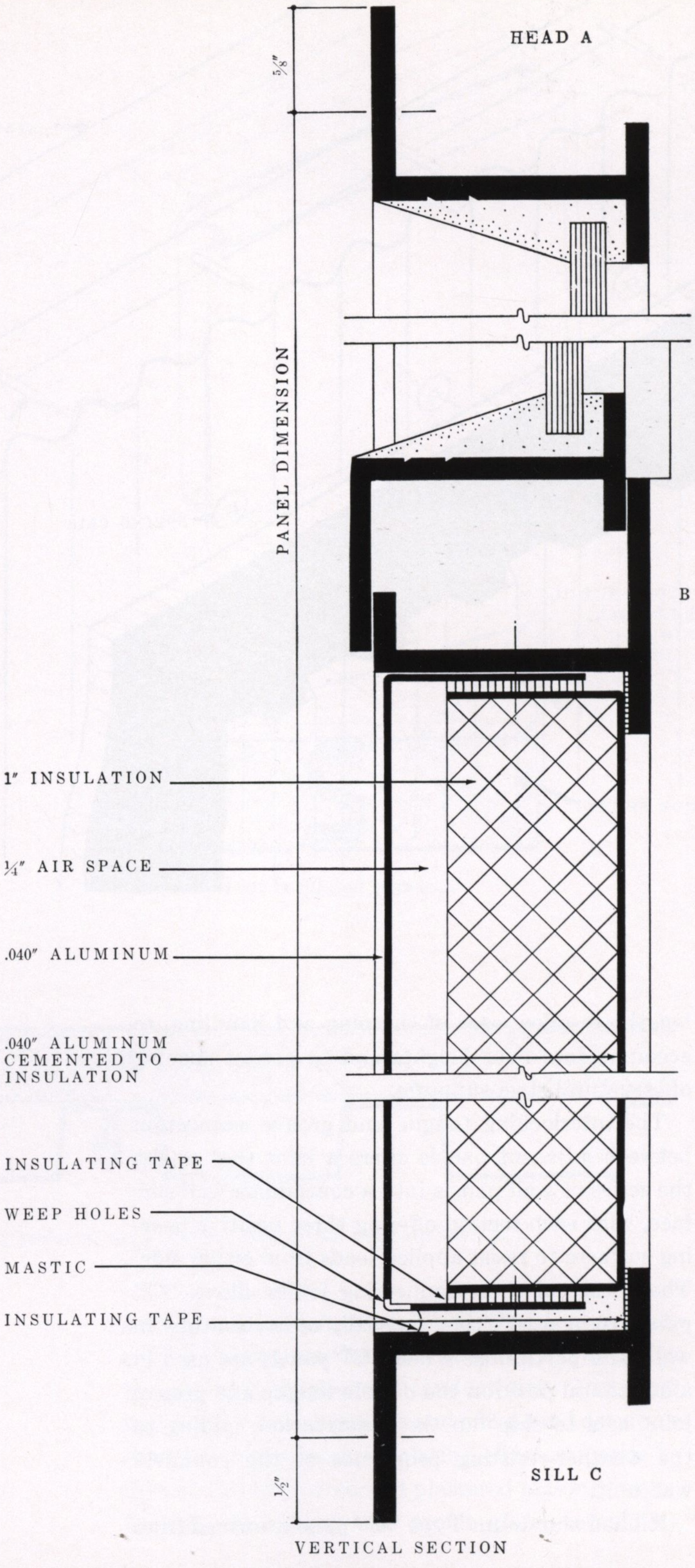
ELEVATION



SECTION B–B

FLOATING TYPE HORIZONTAL MOVEMENT PROVISION

Figure 7-132: Floor-to-floor wall panel.



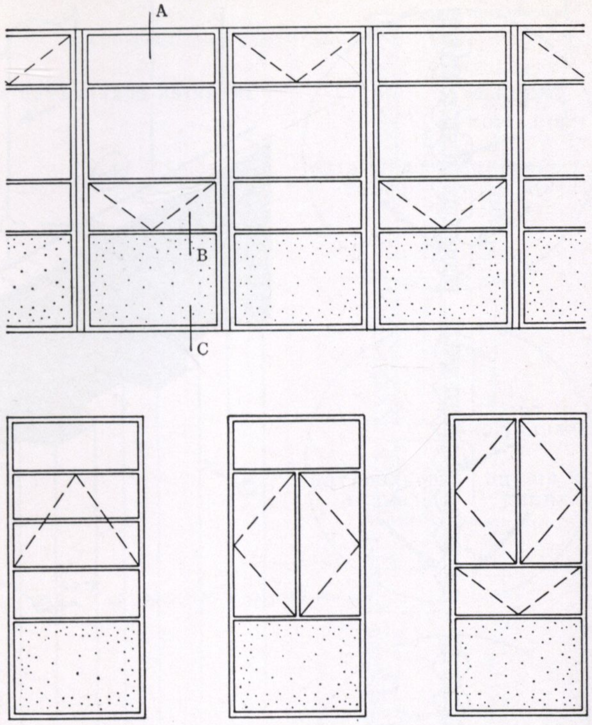
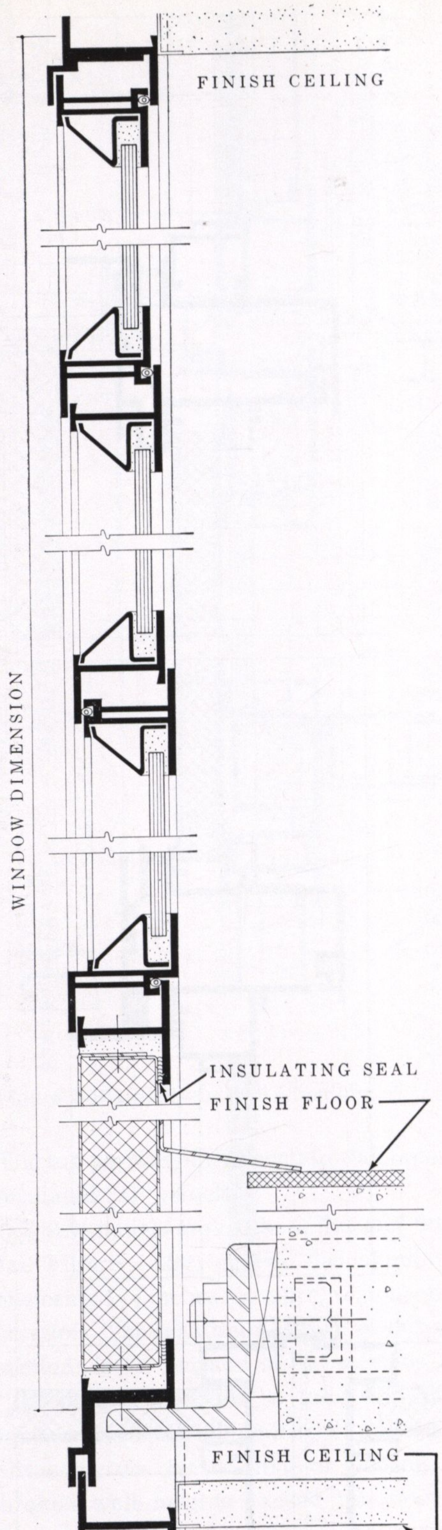


Figure 7-131: Curtain wall units and elevation detail.

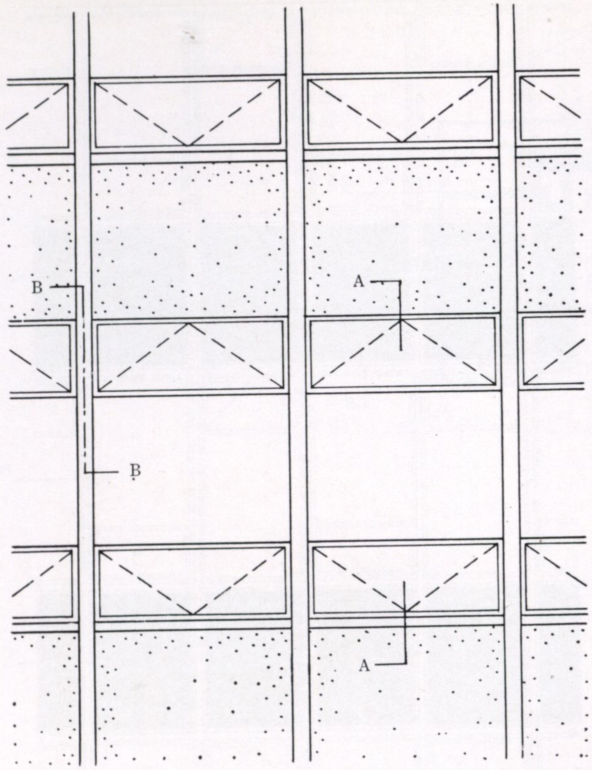
16 B & S gauge mill finish alloy are designed to offer additional architectural treatment by providing long narrow rib lines. The ribs are shallow, semicircular, inturned flutes of approximately 3/8-inch opening, 3/16-inch deep. Four ribs are spaced evenly across the face of the panel and so formed that when a wall elevation is viewed in its entirety, the ribbed lines and the lines of the side lap blend together. In addition to providing architectural treatment, the metal panels are stiffened against compression and wind loads by the ribs.

Figure 7-129 shows the use of the "Q" panel. This industrial building (designed by Raymond & Rado for the Electrolux Corp. in Old Greenwich, Conn.) illustrates the combination of various elements that best meet the requirements in the particular areas. Above the bottom section of the wall, built of masonry for resistance to impact, there is a continuous glass area composed of a top and bottom strip of aluminum ventilating sash and an 8-foot middle strip of glare-reducing fixed corrugated glass with aluminum cover plates at the vertical joints.

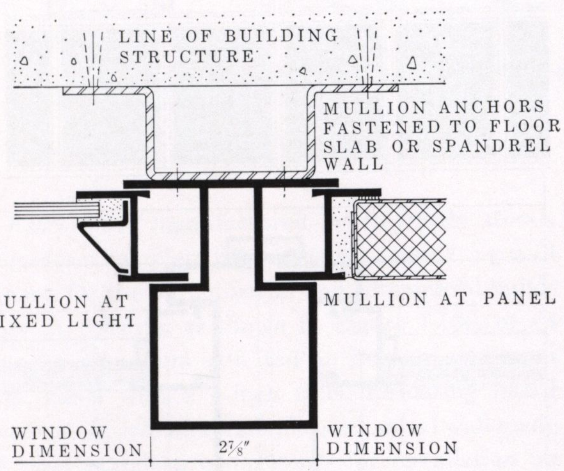


SECTION A-A

FLOATING TYPE VERTICAL MOVEMENT PROVISION



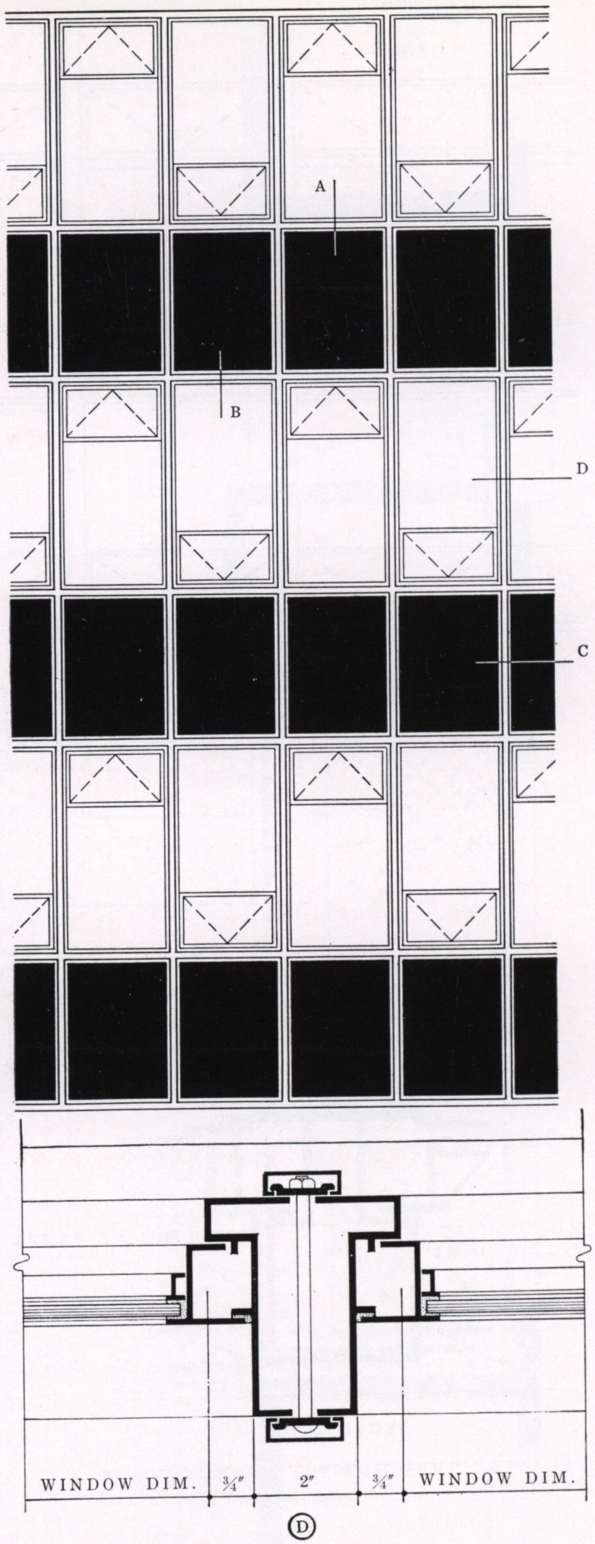
ELEVATION



SECTION B-B

FLOATING TYPE HORIZONTAL MOVEMENT PROVISION

Figure 7-132: Floor-to-floor wall panel.



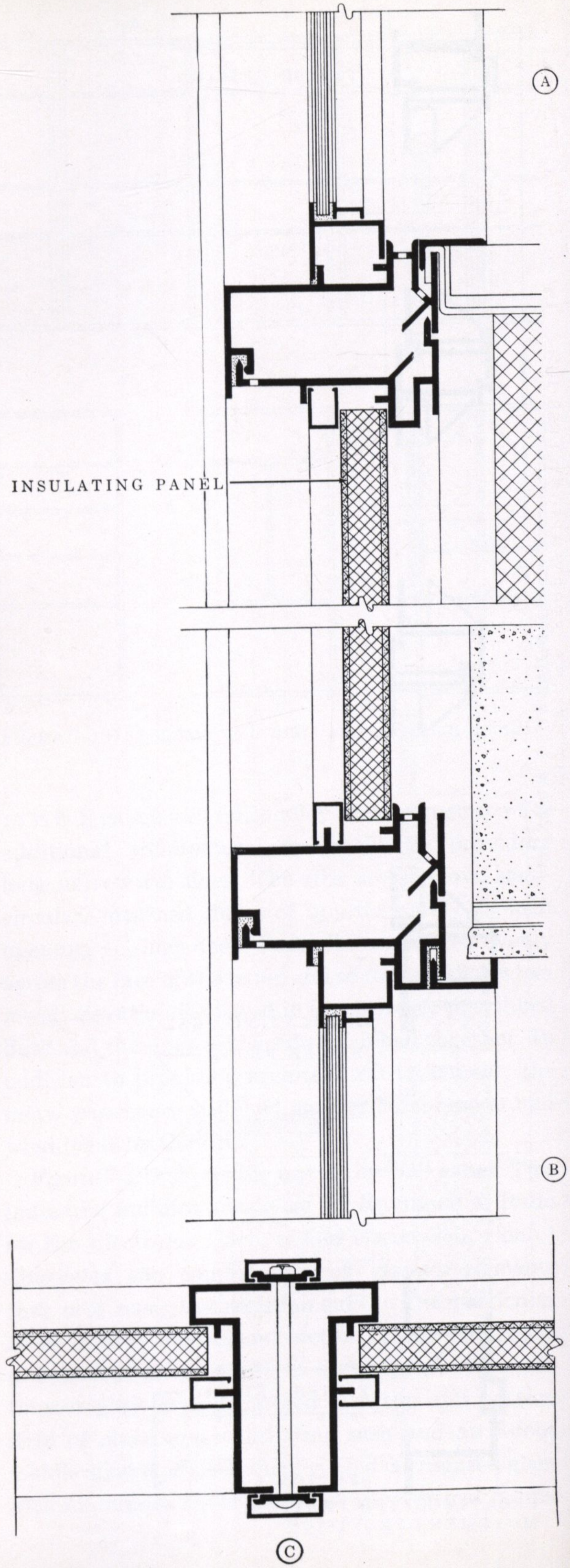


Figure 7-133: Curtain wall system.

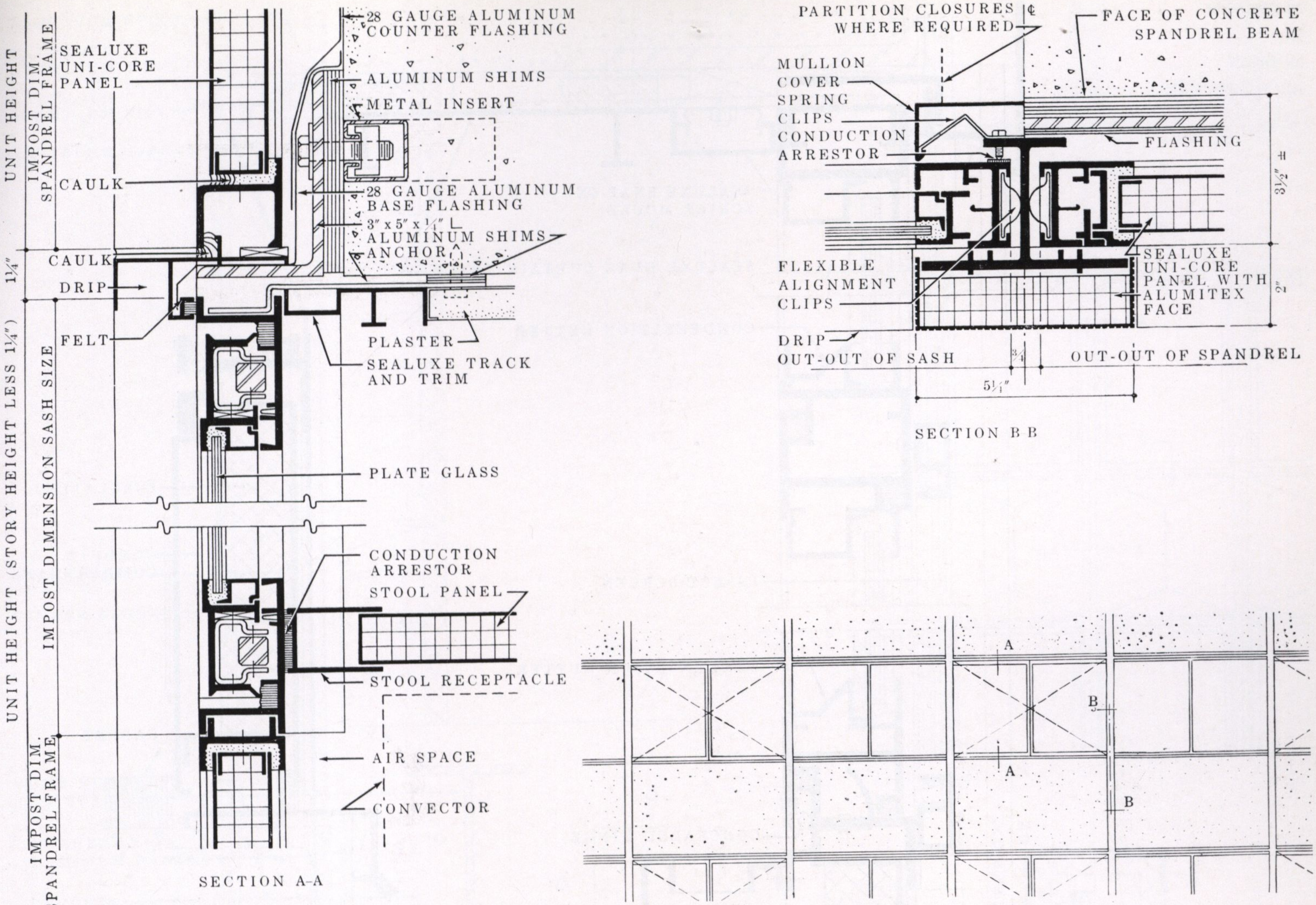


Figure 7-134: Curtain wall assembly.

The top portion of this curtain wall is constructed of insulated "Q" panels.

These panels are made of flat and fluted (see detail Figure 7-129) or two flat aluminum sections enclosing 1½ inches (or more) of noncombustible insulation. The maximum length of fluted aluminum sections is 18 feet and of flat sections 16 feet. The "Q" panels, designed to take the specified wind load, arrive at the job cut to fit and are fastened to the structure by welding or bolting. Where unbroken wall heights exceed the maximum panel lengths, ends can be die-set to provide a tight counterflashed joint.

Reyconowall manufactured by Reynolds Metals provides a complete field-assembled insulating wall system for use on industrial and commercial buildings. It consists, as shown in Figure 7-130, of an exterior aluminum skin and an interior aluminum wall panel with a 1-inch thick insulating board between. It provides a simple economical wall made of three standard components for installation on erected steel girts.

Exterior walls are formed of ribbed or corrugated aluminum siding material used for industrial and commercial construction. Three forms are available: (1) 4-inch rib, .032, .040 or .050-inch thick; (2)

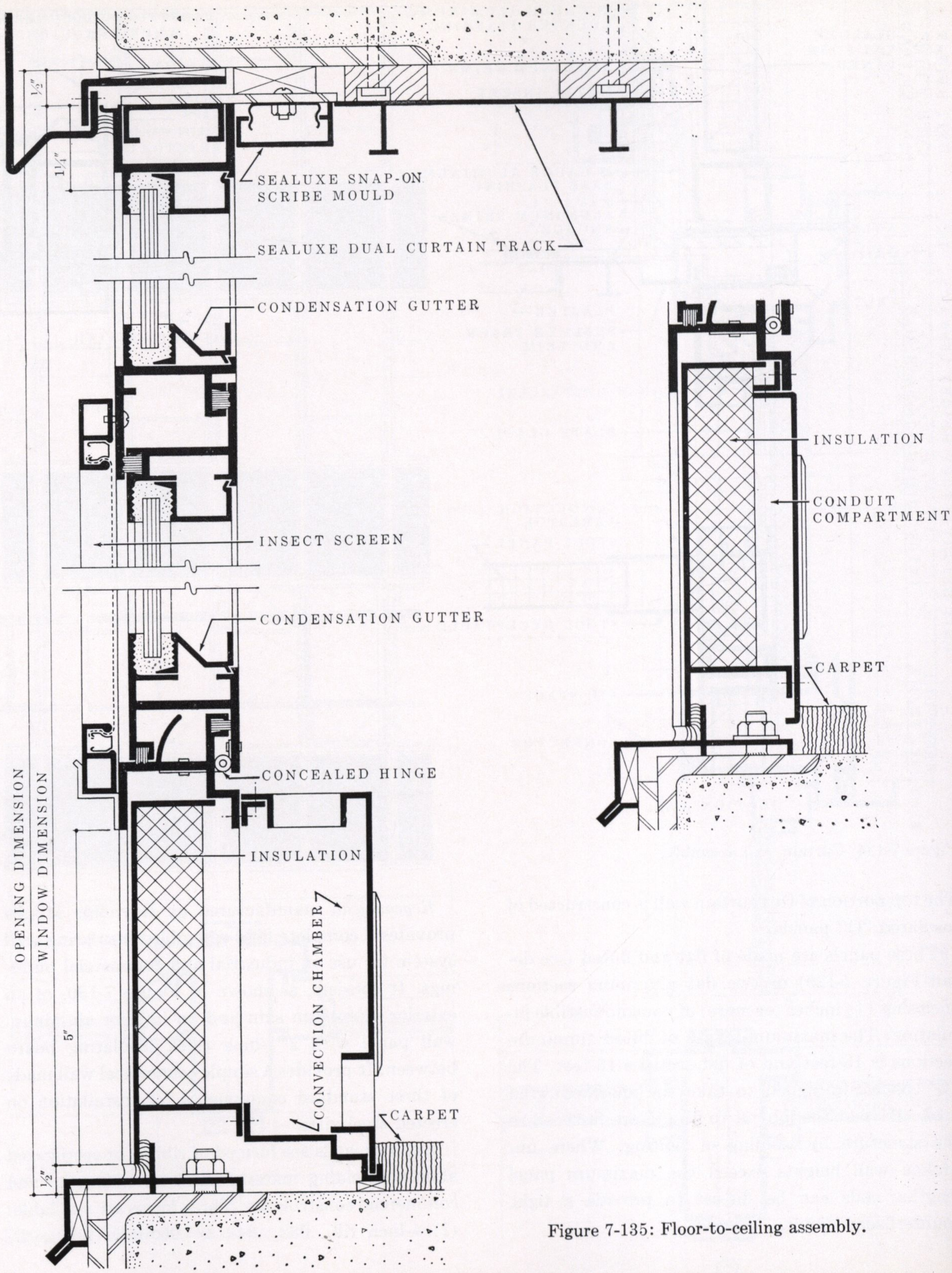


Figure 7-135: Floor-to-ceiling assembly.

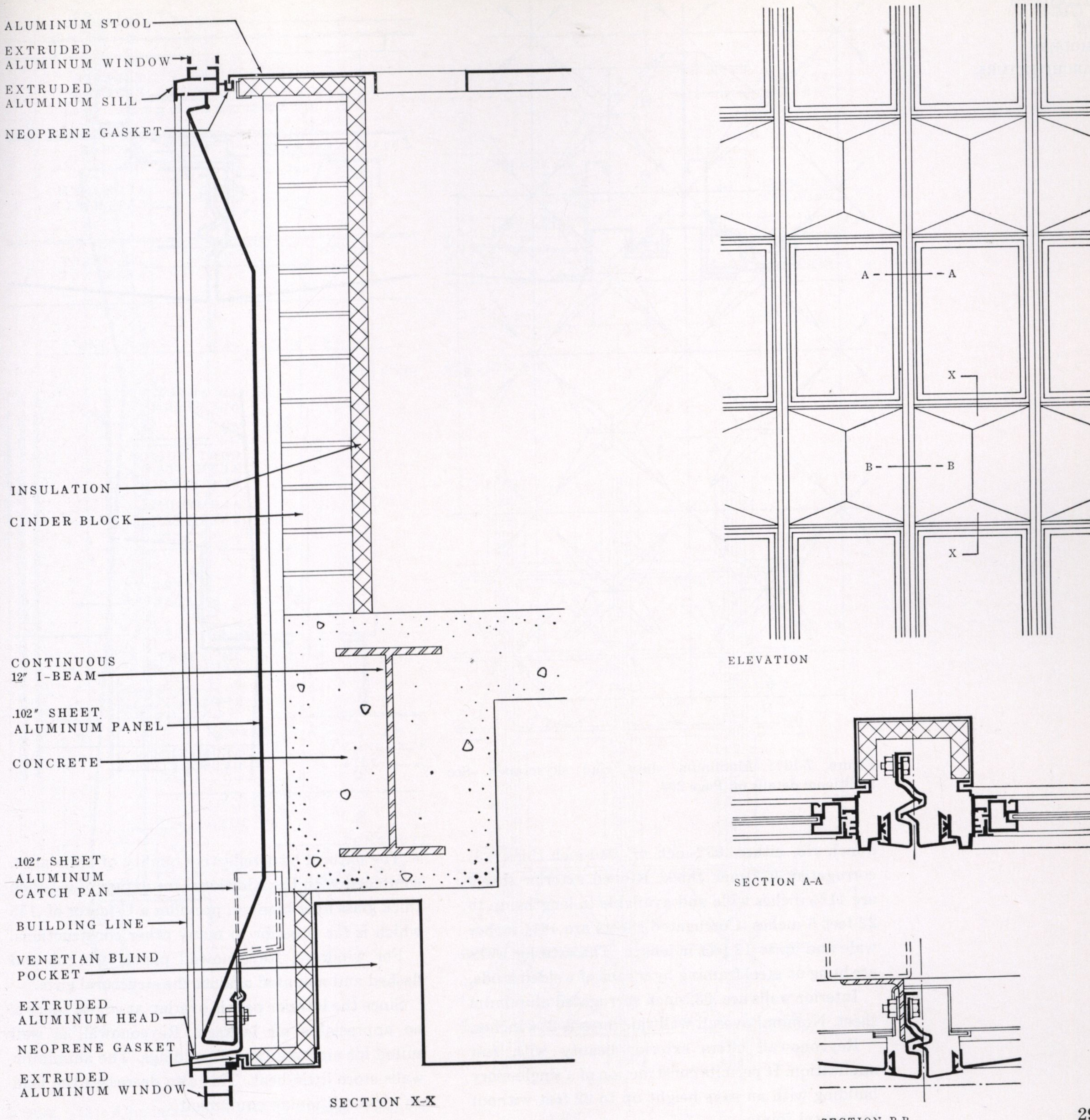
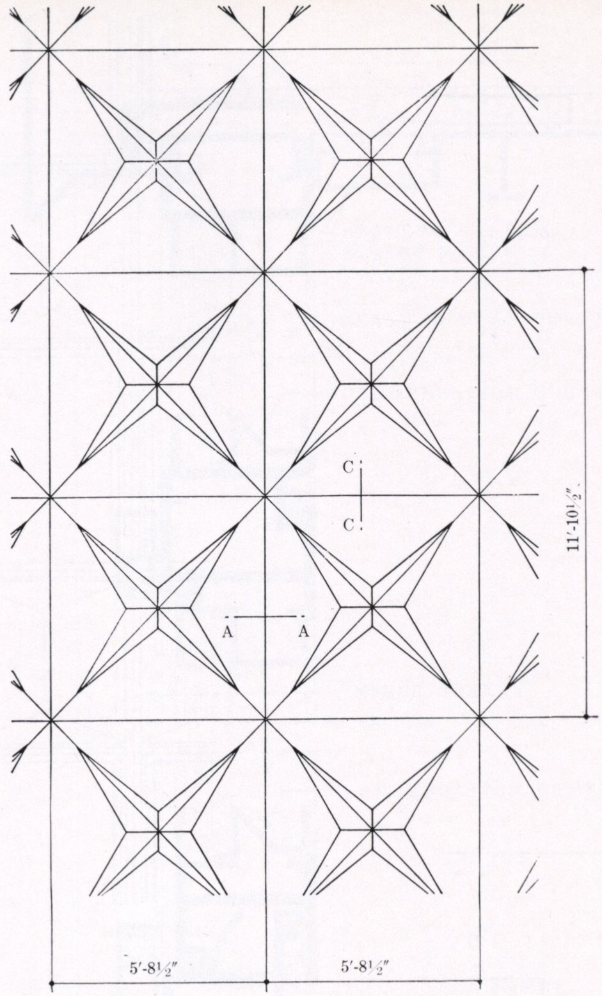
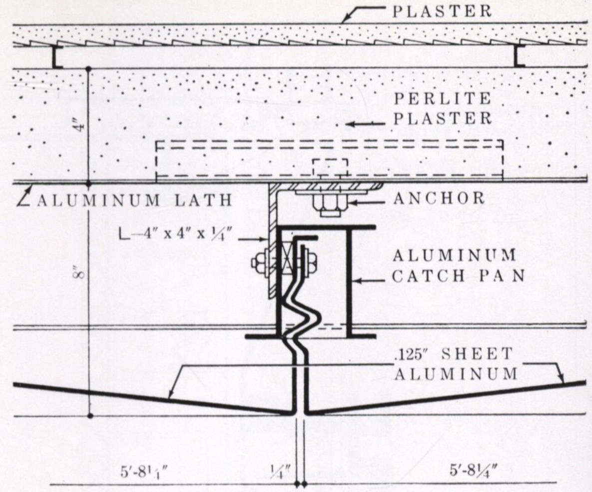
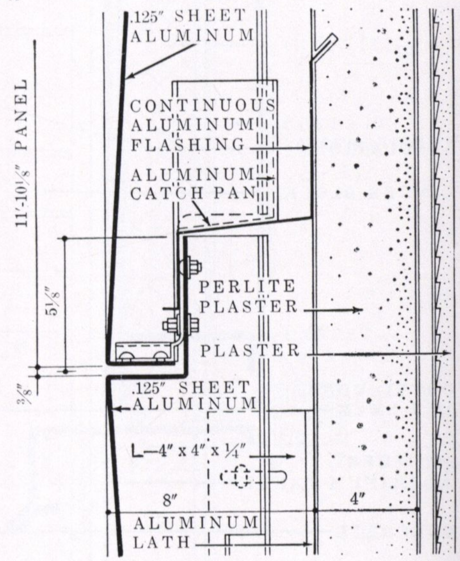


Figure 7-136: Aluminum sheet building enclosure.





SECTION A-A



SECTION C-C

Figure 7-137: Aluminum sheet clad skyscraper. See additional details on Page 293.

8-inch rib, either .032-inch or .040-inch thick; (3) corrugated .032-inch thick. Ribbed exterior sheets are 41⅝ inches wide and available in lengths up to 22 feet 5 inches. Corrugated sheets are 48⅓ inches wide and up to 12 feet in length. The exterior walls are hung on steel framing by means of welded studs.

Interior walls are .032-inch corrugated aluminum sheet. Nominal overall wall thickness is 2⅞ inches.

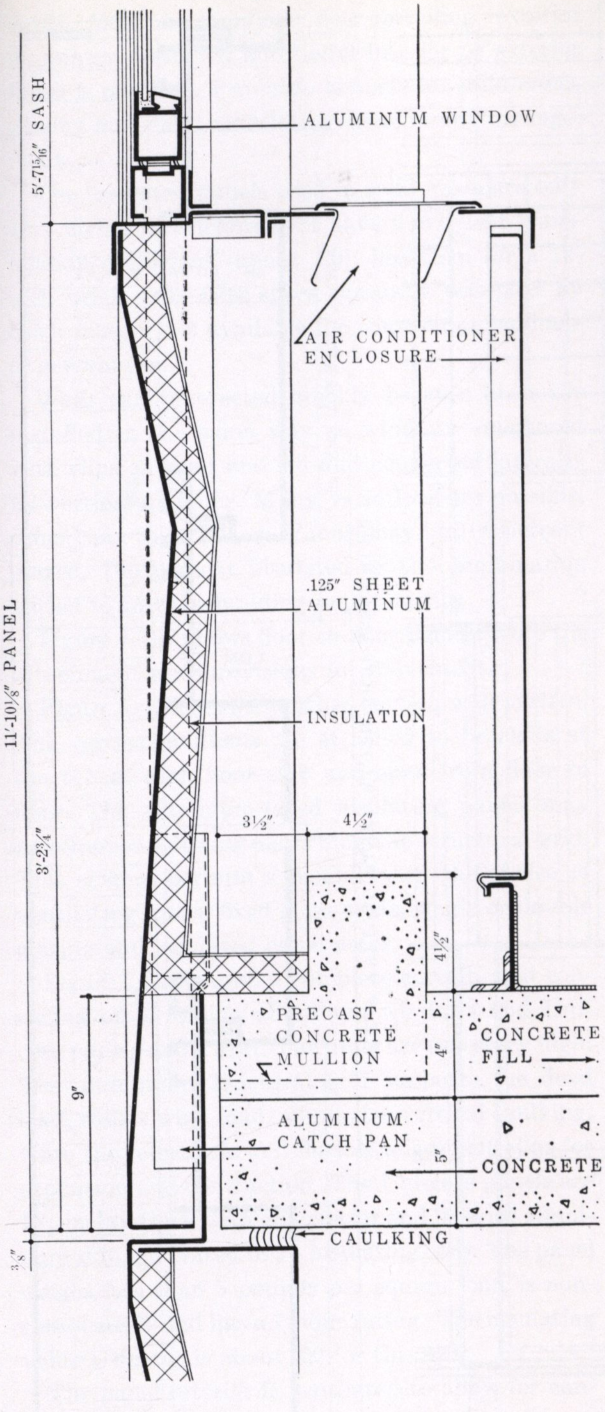
Reyconowall offers exterior beauty with fast application. It permits construction of a single-story building with an eave height up to 22 feet without horizontal joints.

The natural heat-reflective quality of aluminum, combined with the additional insulation of a 1-inch thick glass fiber blanket, provides a U-factor of .155 which is far superior to many other constructions.

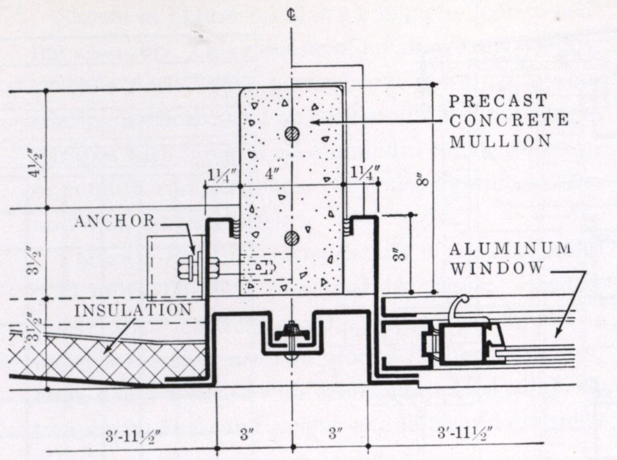
For windows, Reyconowall panels are cut and flashed and mounted against the structural girts.

Since the interior panels overlap at edges, there is no appreciable air leakage. Reyconowall is well suited for air-conditioned buildings. The aluminum walls store little heat. This also decreases the load on air-conditioning equipment.

The entirely different units shown in Figure



SECTION D-D



SECTION B-B

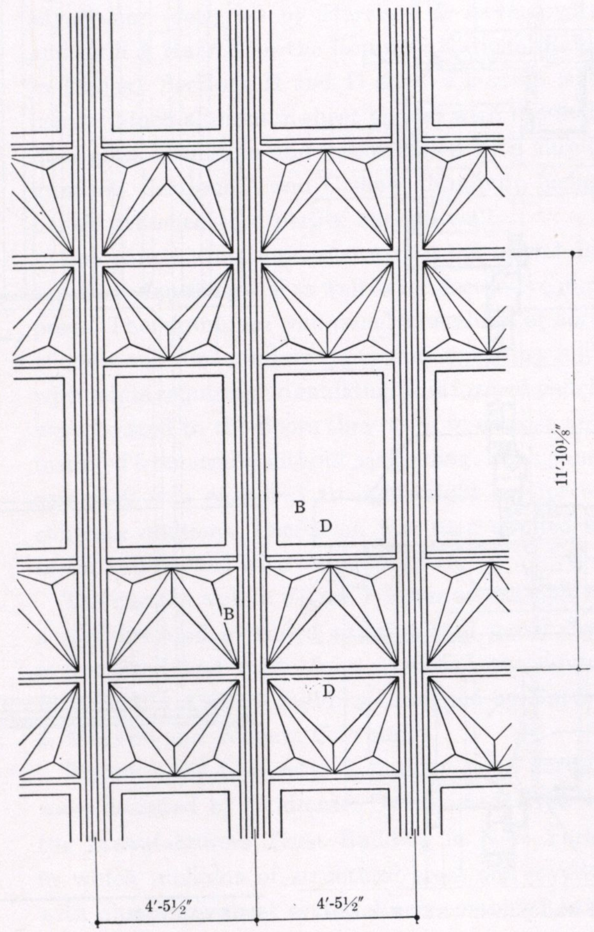


Figure 7-137: Aluminum sheet clad skyscraper. These details concluded from Page 292.

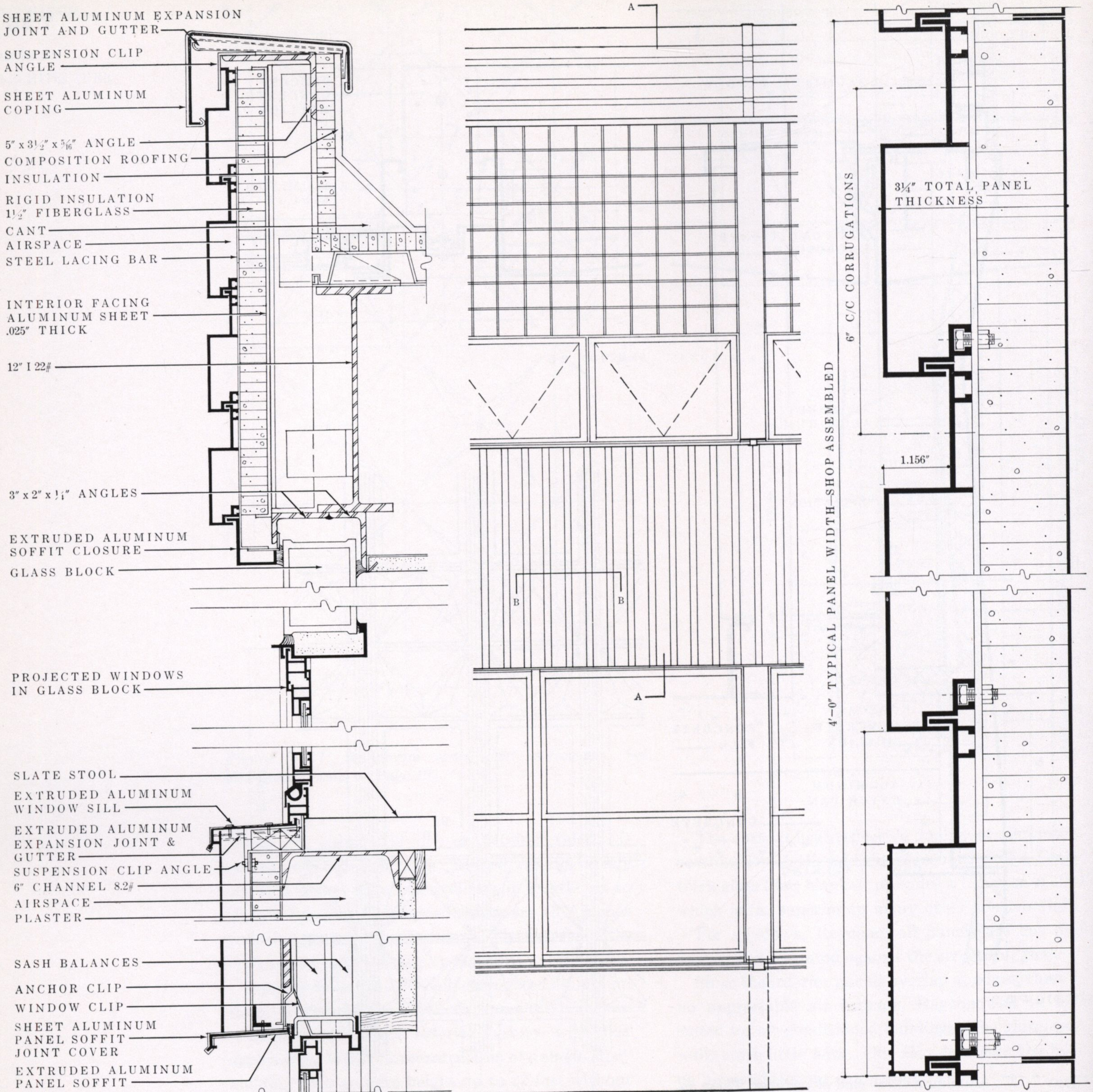


Figure 7-138: Extruded insulated wall panel.

7-131 form a complete floor-to-ceiling exterior aluminum wall. No additional interior or exterior finish is required. Provision is made for solid areas, glazing areas and ventilating areas in any arrangement.

The insulated panels used in solid areas are only $1\frac{7}{16}$ inches in thickness yet have a low heat transmission coefficient (about .20), less than for a 12-inch brick wall. The space normally occupied by thick masonry is available for convectors, cabinets or general use.

Walls can be erected quickly because units are installed in the same way as windows—anchored with clips at head and sill and connected laterally by vertical mullions. Many variations are possible, other than those shown. Panels may be 100 percent glazed, 100 percent insulated or the combination varied to suit the building requirements.

Figure 7-132 shows floor-to-floor panels. Note the attachment and provisions for movement.

Figure 7-133 shows another curtain wall system. The vertical mullions are attached to brackets at the top of each floor slab and span from floor to floor. The aluminum-faced insulating panels may be removed without disturbing the structural grid. This system permits a flexibility in the choice of ventilating areas, fixed glass areas, single or double glazing and insulated panel areas.

Figure 7-134 shows a complete curtain wall consisting of bi-folding aluminum windows and Uni-core panels and a grid. The units are one story high. The aluminum structural grid supports the dead load, resists wind load, eliminates vertical caulking. Note the tolerances and flexible alignment clips for expansion and contraction. The Uni-core panels are $1\frac{3}{8}$ inches thick with an exterior and interior aluminum skin laminated to an insulating core. The panel weighs less than 5 pounds per square foot, is non-combustible and has a 1-hour rating. The insulating value U-factor is about .20 for this unit.

The panel interior is ventilated to allow for condensation and re-evaporation without damage to core or skins. The bottom edge of the panel has provisions for condensation escape and the frame has weepholes. This panel is used also for the window stool.

Shown in Figure 7-135 is a complete floor-to-ceiling assembly. This consists of an aluminum window (with a fixed upper portion and in-swinging ventilating sections) and an insulated aluminum-faced parapet with integral all-aluminum convector cover or conduit compartment. Note also aluminum trim and dual curtain track.

Figure 7-136 illustrates details of an aluminum clad office building (designed by Emery Roth & Sons) with conventional masonry backup. The panel assemblies are two stories (21 feet 3 inches) high, 4 feet 8 inches wide and contain two windows, two sheet panels and a right-and-left-hand extruded jointing that requires no caulking.

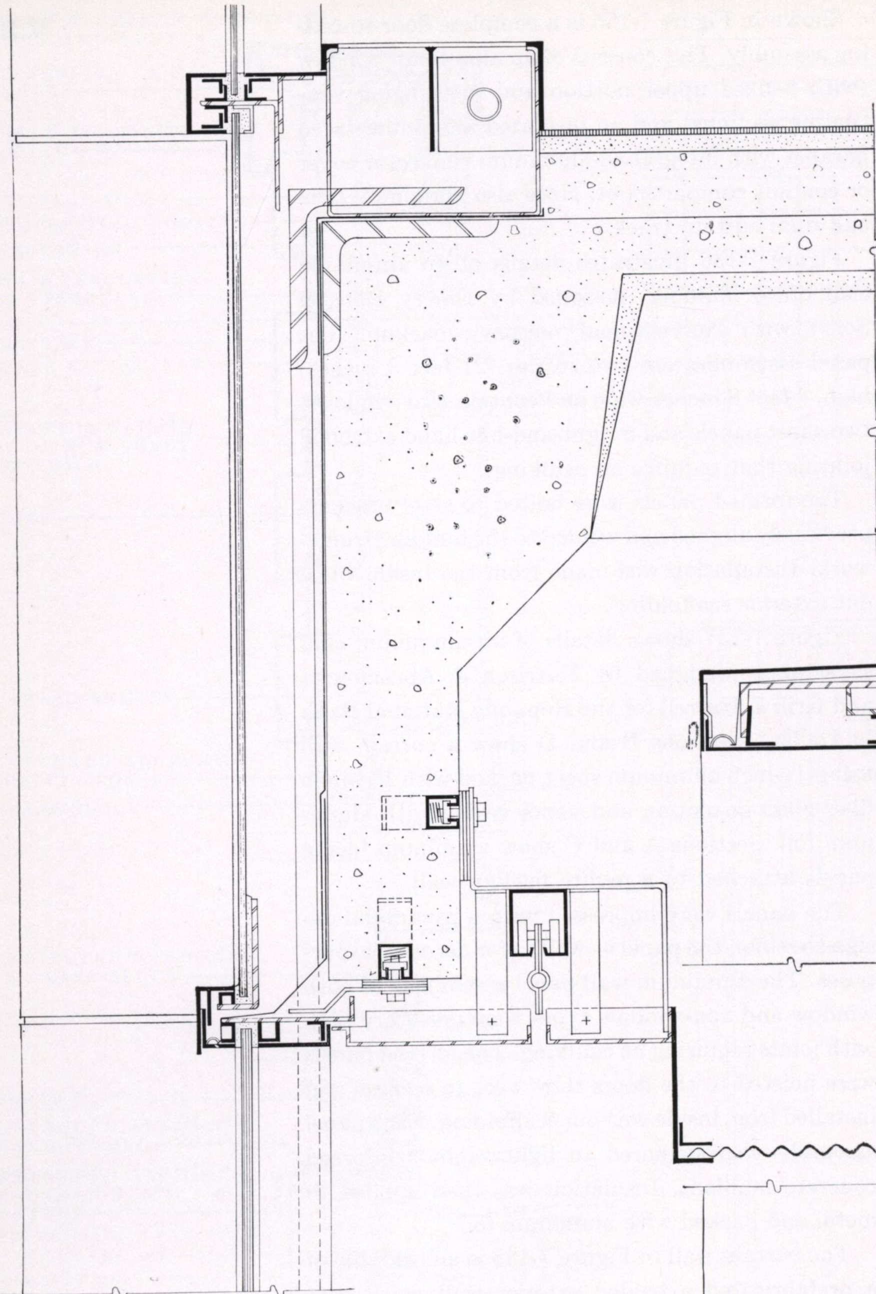
The formed panels were bolted to steel brackets previously aligned and welded to the building framework. Installation was made from the inside without exterior scaffolding.

Figure 7-137 shows details of an aluminum clad skyscraper (designed by Harrison & Abramowitz and Grill & Harrell for the Republic National Bank in Dallas). Sections B and D show a curtain wall using $\frac{1}{8}$-inch aluminum sheet backed with $1\frac{1}{2}$-inch fiber glass insulation and vapor sealed with aluminum foil. Sections A and C show aluminum facing panels attached to a perlite backup wall.

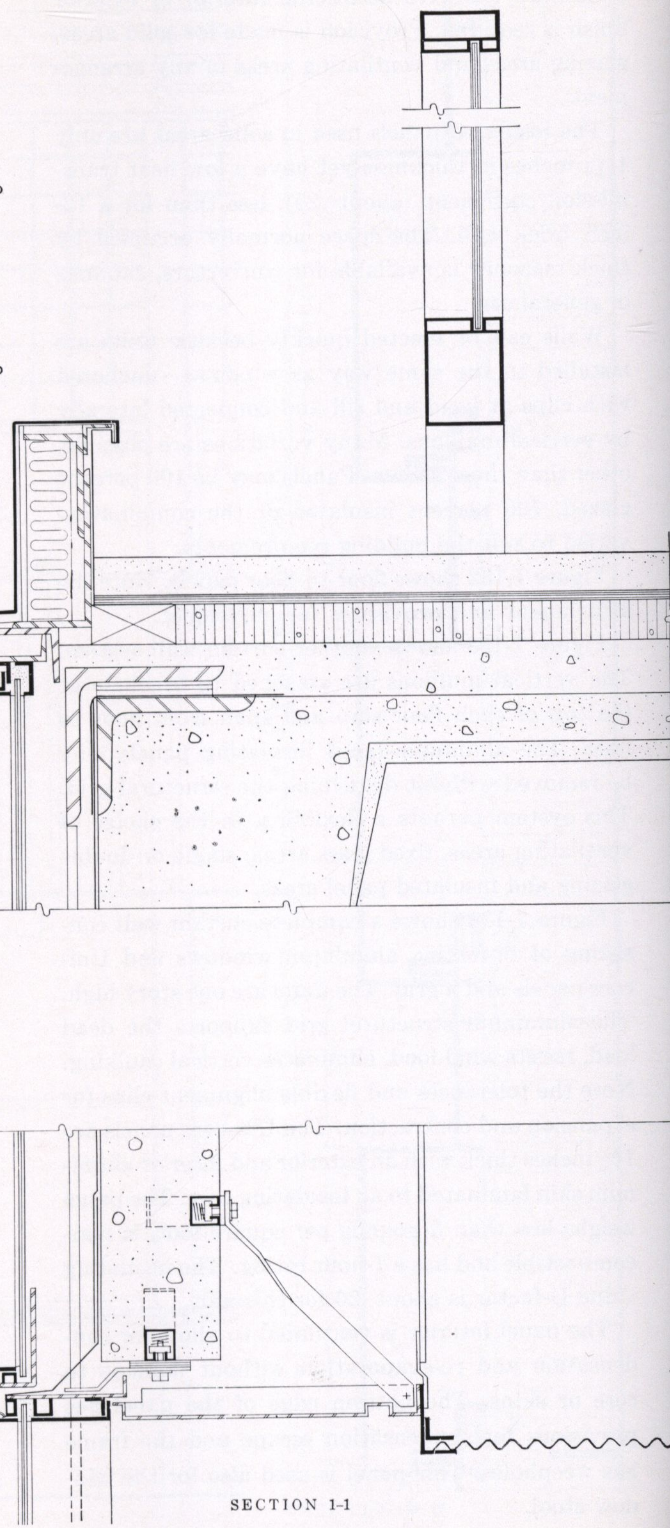
The panels were impressed with a pyramidal design to stiffen the panel as well as for decorative purposes. The aluminum wall panel assemblies of both window and non-window types were one-story high with joints requiring no caulking. The formed panels were hoisted to the floors they were to enclose and installed from inside without scaffolding. Each panel assembly was anchored to lightweight reinforced concrete mullions. Insulation was then applied to metal and backed with aluminum foil.

The curtain wall in Figure 7-138 is an example of a prefabricated extruded exterior wall panel that is insulated and made from extruded aluminum. It is used in a school building (designed by Button & McLean and William C. Young).

Figure 7-139 illustrates a mullion type curtain wall (designed by Skidmore, Owings & Merrill for the Manufacturers Trust Building in New York) in which mullions of structural steel are covered with aluminum sheet material and combined with

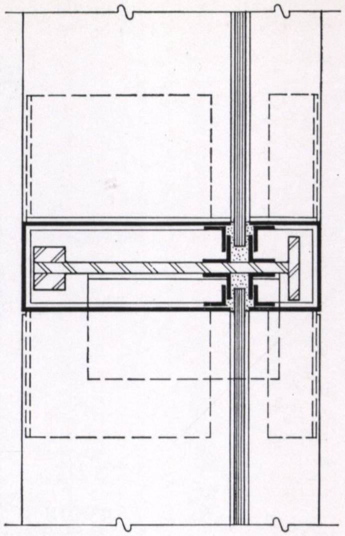


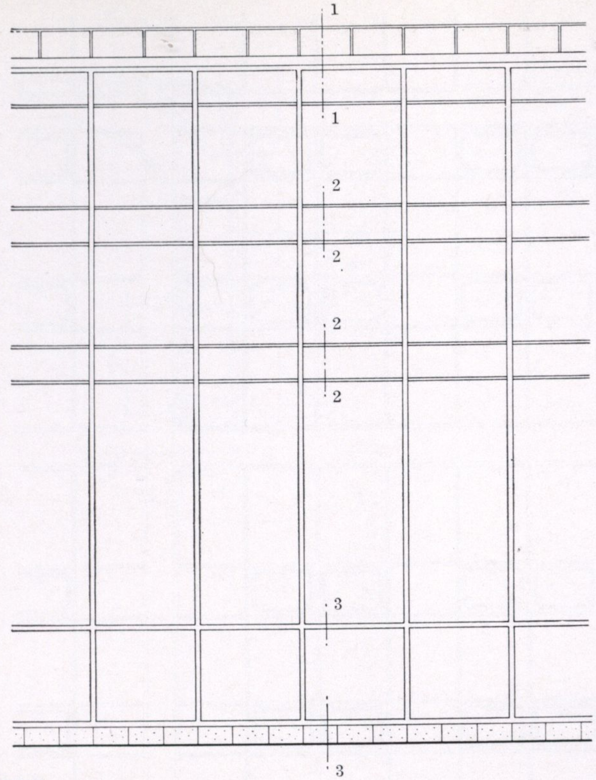
SECTION 2-2

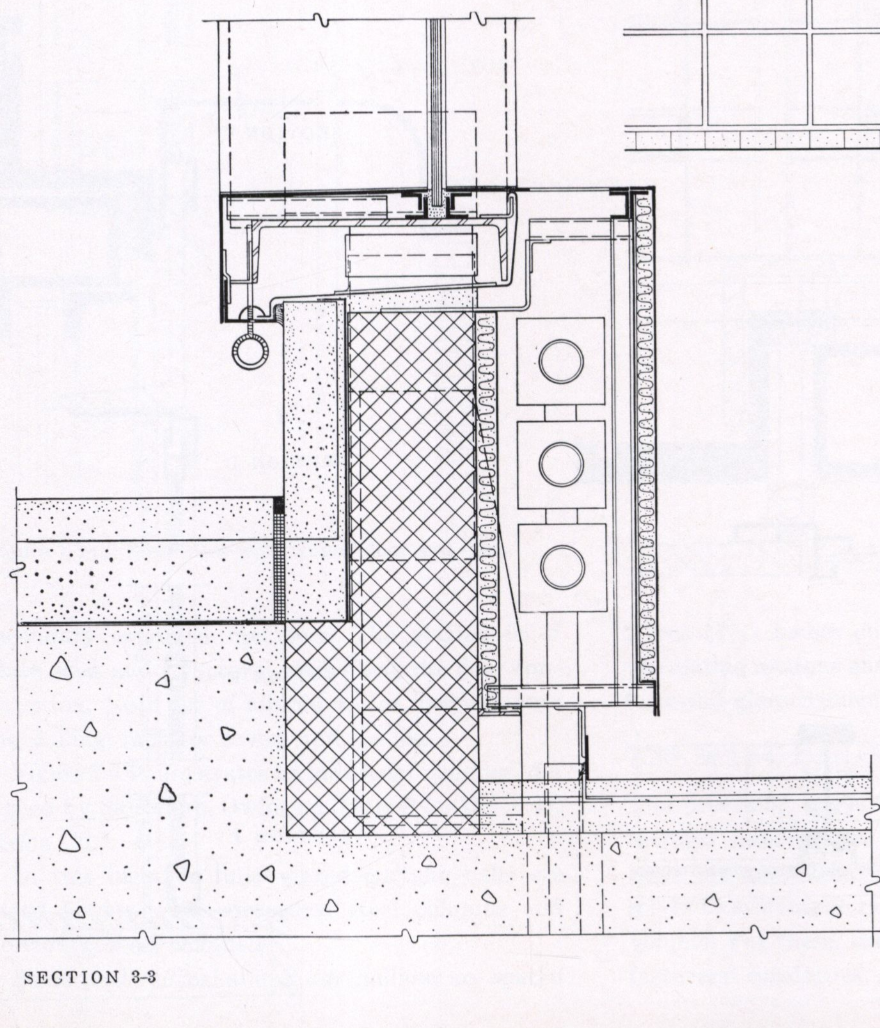


SECTION 1-1

Figure 7-139: Mullion type curtain wall. Concluded on Page 297.

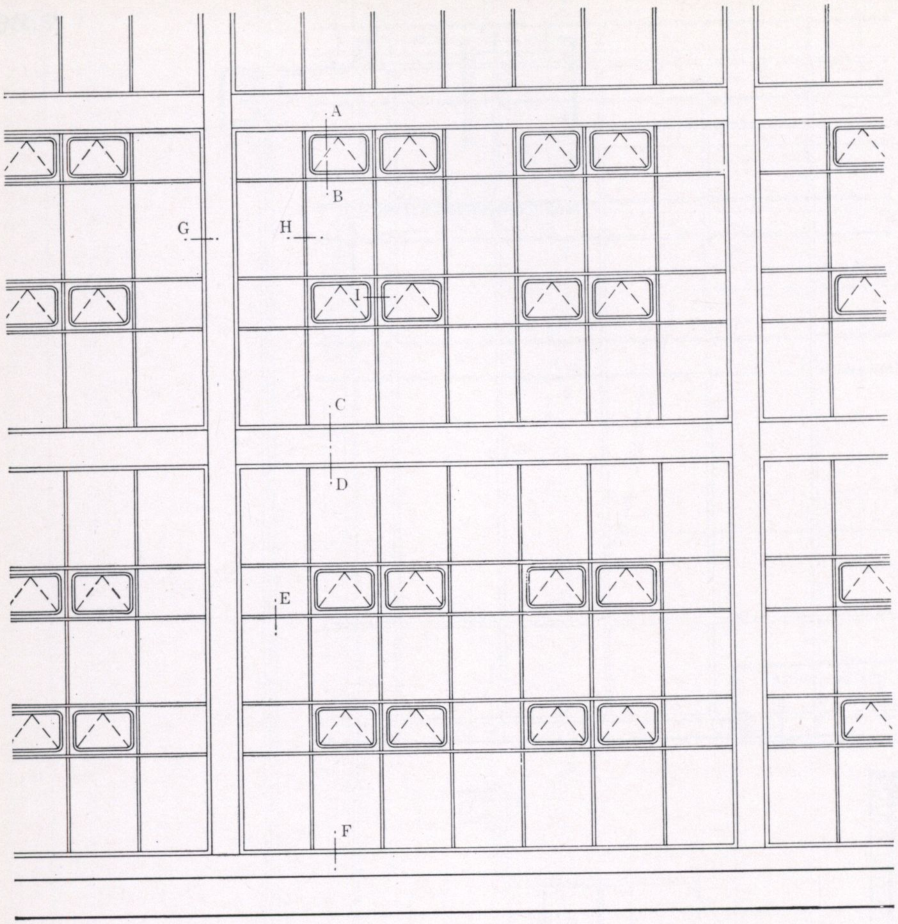


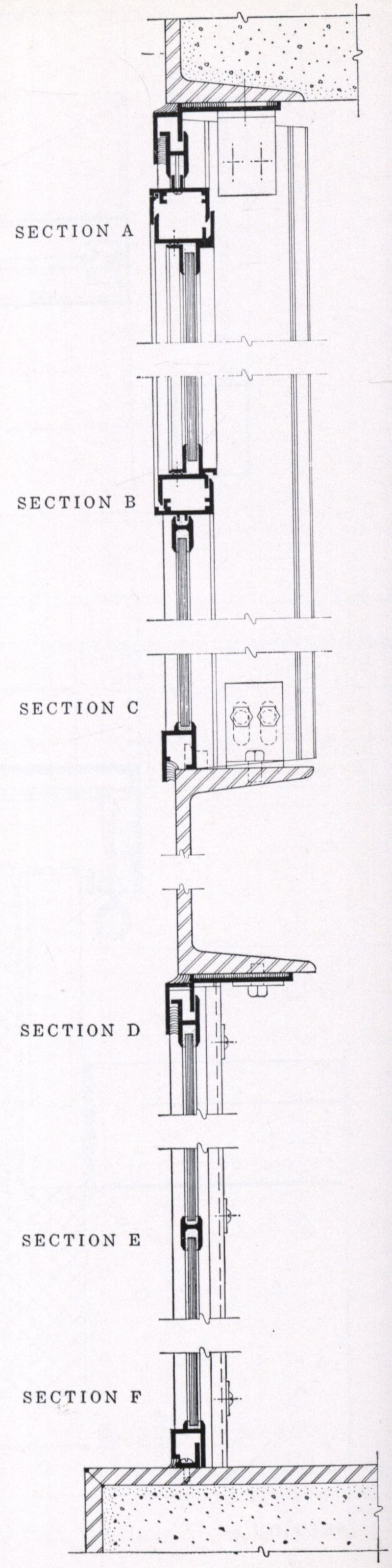


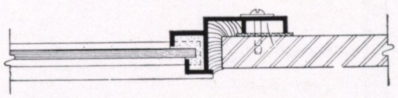


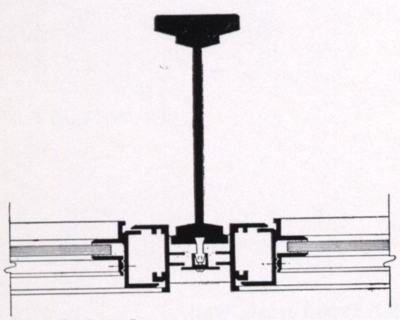
SECTION 3-3

Figure 7-139: Mullion type curtain wall. Concluded from Page 296.









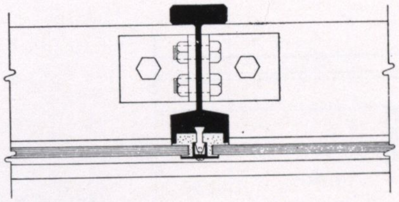


Figure 7-140: Fully glazed extruded mullion type curtain wall.

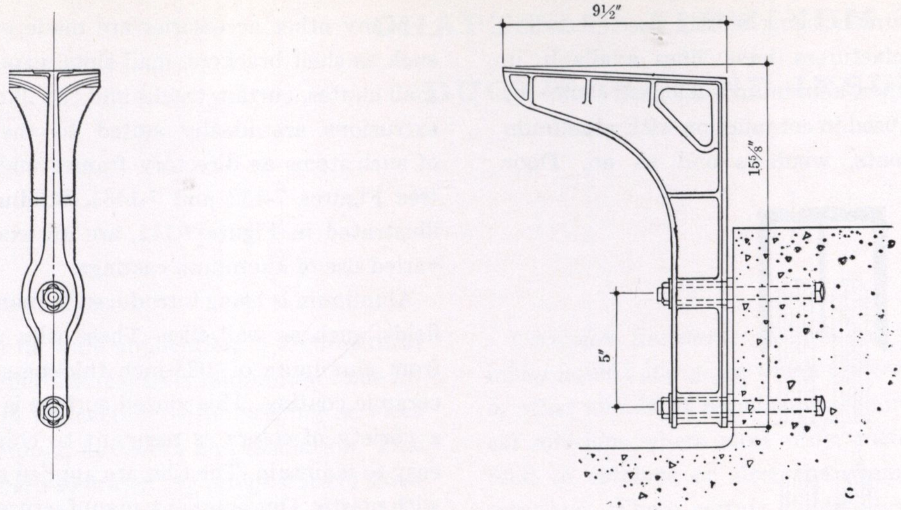


Figure 7-141: Stadium seat bracket.

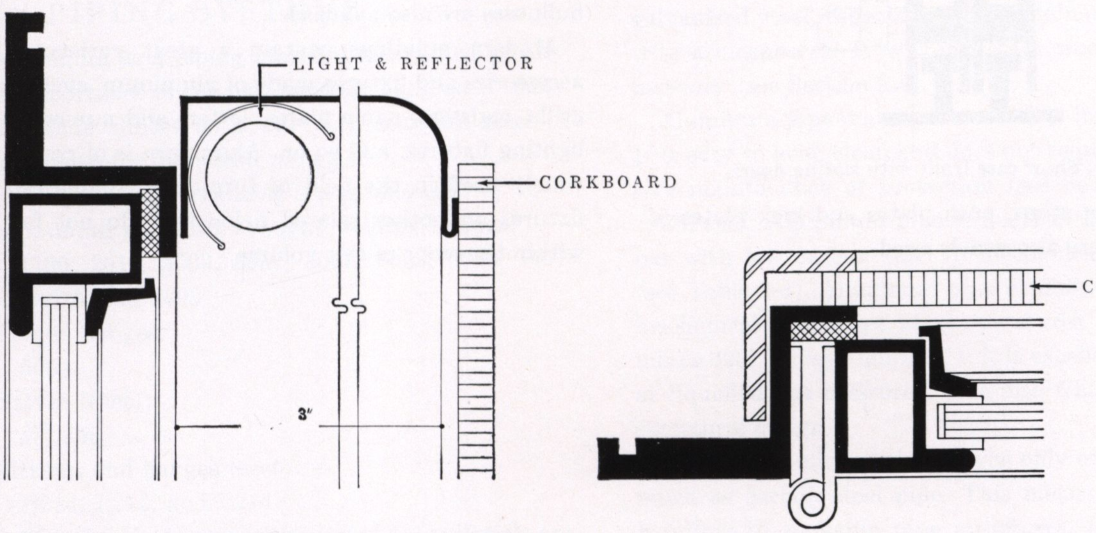


Figure 7-142: Show case with hinged door and light.

secondary extruded members. The glazing is of plate glass and structural glass along the floor construction. Note use of aluminum for flashing, coping, railing, radiator covers and the like.

Figure 7-140 illustrates an industrial building (designed by Skidmore, Owings & Merrill for the J. H. Heinz Co.).

In this instance fully glazed curtain walls are fitted between the structural steel columns and horizontal steel channels.

Structural vertical aluminum mullions are spaced 2 feet 11⁷⁄₁₆ inches on center to receive projected ventilating sections and fixed glazing of translucent, heat-and-glare-reducing hammered glass.

7.26 MISCELLANEOUS

The preceding pages indicate the principal architectural applications of aluminum. In addition, there are many other uses that do not lend themselves to systematic review within the scope of this volume. For these, the reader is referred to manufacturers' catalogues. For instance, builders' hard-

ware of aluminum is being widely used. Leading hardware manufacturers have lines available in aluminum. Further, aluminum is a logical choice for hardware items used in conjunction with aluminum doors, store fronts, windows and so on. Door

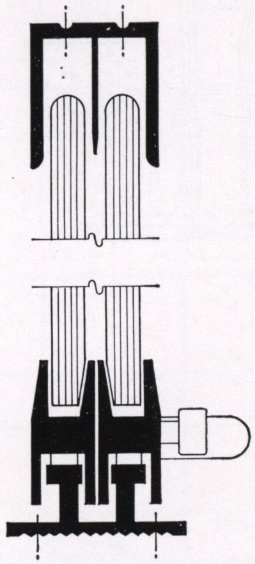


Figure 7-143: Show case front with sliding doors.

closers, door stops, push plates and kick plates of aluminum are also widely used.

Many other accessories are made of aluminum, such as shelf brackets, mail slots, exposed parts of mail chutes, curtain tracks and the like. Aluminum extrusions are ideally suited to the fabrication of such items as directory frames and show cases (see Figures 7-142 and 7-143). Stadium brackets, illustrated in Figure 7-141, are an example of the varied use of aluminum castings.

Aluminum is being introduced in many other new fields, such as wall tiles. These tiles are stamped from aluminum of .025-inch thickness and have a ceramic coating. This glazed surface is available in a variety of colors, is resistant to chipping and is easy to maintain. The tiles are applied economically with mastic. One company manufactures the following sizes: 4¼ x 4¼ inches, 4¼ x 8½ inches, 8½ x 8½ inches. Trim tile, cove base, corner coves and bullnoses are also available.

Modern buildings contain a great variety of accessories and fixtures made of aluminum, such as grills, registers, name plates, letters and numerals, lighting fixtures, and so on. Aluminum is of course widely used in the field of furniture, commercial fixtures and other related fields that do not fall within the scope of this volume.

CHAPTER 8: ALUMINUM PIPING, DUCTWORK AND INSULATION

In addition to its wide application in architectural details and structural elements, aluminum finds increasing use in connection with building services that involve piping, ductwork and insulation. This chapter is devoted to presenting design data in these fields of particular interest to the architect.

8.1 USE OF ALUMINUM IN PIPING SYSTEMS

Aluminum as a piping material has gained greatly in importance in the past several years, until today it stands almost on a par with stainless steel in usefulness for industrial piping.

Alloys usually available are as follows:

Aluminum pipe and wrought welding fittings:
1100, 2014, 3003, 5052, 6061, 6062, 6063, 7075 and Alclad 3003

Forged flanges:
5053

Valves (cast):
43, 356

Fittings and flanges (cast):
B214, F214, and L214

The chemical compositions of these materials are given in Table 2-3. Tables 2-4 and 2-5 give their physical properties. ASTM Specifications for tensile strengths are given in Table 2-6. ASTM Specification B 178-56T and B 26-56T, applying to pressure vessels and castings respectively, are also available.

Among the advantages of aluminum and its alloys, which deserve consideration in setting up specifications for piping materials, are high strength, light weight, good thermal conductivity, resistance to corrosion, passivity when in contact with numerous corrodents, high scrap value, and absence of sparking characteristics. These qualities make aluminum an important piping material.

Corrosion Resistance: Aluminum safely handles many liquids and gases which are corrosive to steel or other metals. It remains passive in many chemical solutions where most other metals and alloys tend to catalyze or alter the chemistry of these solutions. Where certain fluids cause mild corrosion, the corrosion products are mostly colorless and non-toxic. It resists weathering better than galvanized steel, especially in contaminated industrial atmospheres. It will not stain woodwork or masonry (see Section 2.4).

Aluminum pipe makes an attractive installation. It is easy to keep clean and does not require expensive maintenance or protection (see Section 2.4).

Strength: Aluminum pipe is made in alloys on a par with low carbon steel in mechanical strength (see Table 2-4). Aluminum pipe exhibits improved mechanical properties at temperatures as low as minus 320° F (see Figure 2-1); it is excellent for use at liquefied gas pressures. (See also Chapter 6 on structural design.)

Weight: Aluminum pipe weighs only one third as much as carbon steel pipe. This means far easier handling of movable pipe structures, faster construction, less worker fatigue, cheaper transportation, less load on structures (see Chapter 2).

Non-Sparking: Aluminum pipe is non-sparking and so is suitable for use in explosive or inflammable atmospheres.

Economy: While aluminum pipe costs approximately twice as much as carbon steel pipe, its price is only about one-fourth as much as copper or copper alloy pipe, and one-seventh as much as stainless steel pipe of the same wall thickness. Even if the stainless steel pipe thickness is reduced to one-fourth that of standard weight, the cost per 100 feet is still nearly twice that of aluminum pipe.

In view of the differences in weight, all price comparisons with aluminum should be made using the price per foot rather than the price per pound.

Table 8-1 lists the relative cost of piping materials.

TABLE 8-1: RELATIVE COST* OF PIPING MATERIALS

Lap Welded Carbon Steel—ASTM A120	1
Seamless Carbon Steel—ASTM 106 Gr. A	1
Wrought Iron—ASTM A72	2
Aluminum Type 3003	2
Aluminum Type 6063	2
Aluminum Type 6061	2.25
Aluminum Type 1100	2.5
5% Chrome Molybdenum ASTM A158 Gr. P5a	4
Copper ASTM B42	7.5
Red Brass ASTM B43	7.5
Silicon Bronze	8
Stainless Steel Type 304 ASTM A213 TP304	13
Stainless Steel Type 347 ASTM A213 TP347	16
Stainless Steel Type 316 ASTM A213 TP316	21

* Based on price per 100 feet of 6-inch standard weight pipe, with carbon steel pegged at 1. See Appendix for source of this and other data.

PHYSICAL AND MECHANICAL PROPERTIES OF ALUMINUM AS UTILIZED IN PIPING SYSTEMS: The Charpy impact strength of wrought aluminum and its alloys is of the order of 10 foot-pounds at room temperature. This is substantially lower than carbon steel but is adequate for piping service. In addition, the toughness of these wrought aluminum materials is not substantially affected by low temperatures down to −320°F. Hence they may be safely used under sub-zero conditions. Cast aluminum alloys, on the other hand, are quite notch sensitive and have a materially lower impact strength. When piping systems are subjected to unusual shock conditions, care should be exercised in the use of the high strength aluminum alloys until further information is available.

There is need for additional data on the as-welded properties of the higher strength aluminum alloys. When such high strength materials are welded, the physical properties of the heat-affected zone (a width of one to five times the wall thickness) are altered by the welding operation. This then raises the question regarding the basis for determining the pressure capacity of the pipe (see Section 4.2). Intensive investigations are under way to determine the answers to this problem.

Thus far aluminum pipe has not been recognized in safety codes such as the Boiler Construction Code of the American Society of Mechanical Engineers and the American Standard Code for Pressure Piping, issued by the American Standards Association, and therefore is not included in their specifications of materials and allowable working stresses. However, it is understood that the code-making bodies have these piping materials under consideration and will soon publish such data. ASME Boiler Code, Section VIII for unfired pressure vessels does provide allowable stresses for type 1100, 3003 and 6061 aluminum sheet and plate for temperatures up to 400°F. From these and from the general principles underlying the allowable working stresses established by code-making bodies, it is possible to draw some conclusions as to suitable design stresses for aluminum piping:

Allowable working stresses for piping falling under the jurisdiction of Section 1 (Power Boilers) of the ASME Boiler Code, Section 1 (Power Piping) and Section 4 (District Heating) of the ASA code for pressure piping are either one-fifth of the ultimate strength or 80 percent of the stress required to produce 1 percent creep in 100,000 hours (both values being determined at the actual operating temperature). The lower of the two values is the allowable working stress.

For oil refinery piping (Section 3 of the Code for Pressure Piping) the allowable working stress is one-fourth of the ultimate tensile strength, or 60 percent of the yield strength, or the stress required to produce 1 percent creep in 100,000 hours, all determined at operating temperature, the lowest value being selected. Chemical process piping in other than oil refineries is not specifically covered

by any of the safety codes. In view of the similarity of the hazards involved, it would appear that the design of chemical process piping should follow the principles established in the oil piping section of the pressure piping code.

Chapter 3 of Section 6 of the Code for Pressure Piping treats expansion and flexibility under the general heading of fabrication details. This chapter gives rules for determining the allowable stress range for the combined stress from bending and internal pressure which should be adhered to in designing aluminum piping systems. The rules given in paragraphs 620 (g) and (h) of this code are as follows:

"(g) Where a piping system is subjected to the occasional temperature changes and to combinations of constant stress and minor cyclic variable stresses associated with the normal operation of the plant, the combined stresses due to bending and pressure shall not exceed three-fourths the sum (of the allowable working stress) for the piping material at atmospheric temperatures and (the allowable working stress) at the nominal operating temperature, but in no case shall the combined stress due to bending and pressure exceed 40 percent of the specified tensile strength of the pipe material at room temperature.

"The longitudinal pressure stress shall be determined by dividing the end force due to internal pressure

$$F = \frac{p\pi d^2}{4}$$

by the cross-sectional area of the pipe wall

$$A = \frac{\pi}{4}(D^2 - d^2)$$

in which p = internal pressure, pounds per square inch; d = nominal outside diameter of the pipe minus two times the nominal wall thickness, inches; and D = nominal outside diameter of pipe, inches."

"(h) Where a piping system is subject to temperature changes of a definitely cyclic nature or to severe vibration that may result in failure by fatigue, the limit of the safe combined stress permitted in paragraph (g) shall be divided by 2."

As indicated above, it is questionable at present whether it is permissible or desirable, in the case of welded aluminum piping systems, to determine the wall thickness of the pipe on the basis of its cold-worked or heat-treated strength; or on the basis of its annealed strength, since the effect of welding is to anneal the pipe for a distance of one to five times the wall thickness from the center line of the weld. Since aluminum piping is not treated by the codes, no direct guidance is available in them.

However, an interpretation (known as Case 994) of Section VIII of the Boiler Code has been made by the Boiler Code Committee. According to this interpretation, when fabricating welded pressure vessels of cold worked 3003 plate, it is necessary to use the allowable working stresses established for annealed 3003 plate in Table U3 of Section VIII in designing the pressure vessel. Experiments are being made with seamless aluminum pipe to determine whether the rule established in Case 994 must be followed or whether it is possible to take advantage of the higher physical properties of cold-worked and heat-treated pipe in spite of the annealing effect of the welding operation. Until these experiments are completed, it would appear necessary for the user either to design welded aluminum piping on the basis of the annealed physical properties or to conduct bursting pressure tests on the type of material he wishes to employ.

Joint efficiencies established in the Boiler Code apply only to longitudinal joints. The efficiency of circumferential or girth welds is considered by the code to be 100 percent. Hence, joint efficiencies need be taken into account only in welded piping systems when the pipe is fabricated from plate by forming into a cylinder and welding the longitudinal seam.

Allowable working pressures for annealed seamless 3003 pipe and butt welding fittings at temperatures up to and including 400°F are given in Table 8-2.

These working pressures are based on the stress value given for annealed 3003 plate in Table U-3 of Section VIII of the Boiler Code multiplied by 1.25. The figure 1.25 has been used to convert the stresses from a factor of safety of five used in Section VIII to a factor of safety of four, as used in the oil piping section of the Code for Pressure Piping.

TABLE 8-2: ALLOWABLE WORKING PRESSURES FOR ANNEALED 3003 ALUMINUM ALLOY PIPE AND WROUGHT SEAMLESS BUTT WELDING FITTINGS

NOMINAL PIPE SIZE INCHES	WEIGHT OR SCH. NO.	WALL THICKNESS INCH	FOR TEMPERATURES NOT TO EXCEED 150°F	250°F	300°F	350°F	400°F
¾	S-40	0.113	660	570	494	424	377
	X-80	0.154	900	770	680	580	520
1	S-40	0.133	620	540	465	398	354
	X-80	0.179	840	720	630	540	476
1¼	S-40	0.140	520	443	387	332	295
	X-80	0.191	710	610	530	453	403
1½	S-40	0.145	467	401	350	300	267
	X-80	0.200	650	560	484	414	368
2	S-40	0.154	397	340	298	255	227
	X-80	0.218	570	482	422	361	321
2½	S-40	0.203	432	371	324	278	247
	X-80	0.276	590	510	441	378	336
3	S-40	0.216	378	324	284	243	216
	X-80	0.300	530	450	394	338	300
3½	S-40	0.226	346	297	260	222	198
	X-80	0.318	487	417	365	313	278
4	S-40	0.237	322	276	242	207	184
	X-80	0.337	459	393	344	295	262
5	S-40	0.258	284	243	213	183	162
	X-80	0.375	413	354	310	265	236
6	S-40	0.280	259	222	194	166	148
	X-80	0.432	399	342	300	257	228
8	S-40	0.322	229	196	171	147	131
	X-80	0.500	355	304	266	228	203
10	S-40	0.365	208	178	156	134	119
	X	0.500	285	244	214	183	163
12	S	0.375	180	154	135	116	103
	X	0.500	240	206	180	154	137
14	S	0.375	164	141	123	105	94
	X	0.500	219	188	164	141	125
16	S	0.375	144	123	108	92	82
	X	0.500	191	164	144	123	109

Note: S = Standard. X = Extra Strong. Numbers are Schedule Numbers.
[1] The above tabular values are rounded off to the next higher unit of 10 for pressures 500 psi and higher. Interpolation is permissible for intermediate temperatures.
[2] The allowable pressures were calculated by the formula given in the American Standard Code for Pressure Piping, ASA B31.1—1942 Section 3, paragraph 325(a), as follows:

$$P = \frac{2S(t_m - c)}{D}$$

where P = allowable pressure in psig. S = allowable working stress in psi. D = outside diameter in inches t_m = minimum thickness in inches or 22½ percent less than the normal thickness shown in the table for wrought iron, and 12½ percent less for aluminum. c = allowance in inches for corrosion and/or mechanical strength, = 0.05 in. for all pipe sizes for wrought iron, = 0 for aluminum (nonferrous).
The allowable working stresses for aluminum correspond to the allowable stresses given for the annealed grade of specification SB 126 in the ASME Boiler Construction Code, 1946 Ed. Section VIII, Table U3, corrected from a safety factor of 5 to one of 4 in conformance with code practice in establishing stresses in the oil piping section.
[4] Plant Process Piping: It is recommended that the allowable working pressures listed above be used also for process piping in plants other than oil refineries (such as chemical industries) except where such piping is expressly covered in the ASME Boiler Construction Code or other sections of the American Standard Code for Pressure Piping.

Cast screwed and flanged aluminum fittings are uniformly rated at 125 pounds per square inch working pressure for service at room temperature. Pressure ratings at higher temperatures must be obtained from the manufacturer of the particular fitting under consideration.

Piping Components: Tables 8-3, 8-4 and 8-5 list the various sizes in which aluminum alloy pipe, tubing, fittings and flanges are regularly available. Pipe and tubing are either extruded or cold drawn. Speaking generally, the cold-drawn product is closer to dimensions than the extruded item, although for most piping purposes either classification should be satisfactory.

Cast flanged and threaded valves are available in sizes from ⅛ to 30 inches in aluminum alloy 43. These valves are available in 75, 100, 125 and 200 pounds per square inch with 18-8 stainless steel stem and wedge. Although the maximum temperature will depend on the service, these valves are recommended for service up to 350°F. For service above this temperature, stainless steel valves should be considered.

APPLICATIONS:

Industrial Plants: Aluminum already holds a position of growing importance in many industries because of its high degree of inertness in the presence of numerous chemicals, in contrast to a large number of metals and alloys which tend to catalyze or alter the chemistry of solutions without themselves entering into the reactions.

Since maintenance of color is often of great importance, another point in favor of aluminum is that its corrosion products are colorless. Some solutions tend to cause slight corrosion, which helps to immunize the aluminum against further attack.

As can be seen from Table 2-8, aluminum exhibits favorable characteristics in the presence of a large number of chemicals, and it is for this reason that aluminum piping is frequently employed in chemical, food, soap and cosmetic plants, and in the petroleum industry.

Because aluminum alloys guard against color degeneration and because they also aid in maintaining quality standards in the handling of fatty

acids, they receive serious consideration from manufacturers of soap and cosmetics. They are also found useful in the construction of equipment for the vacuum distillation of these acids, where the separation of the acid from the mixed solution is accomplished by heat transfer.

In the petroleum industry, both in the production field and the refinery, resistance of aluminum to corrosive attack by hydrogen sulphide and sour crude oils, mineral oils and liquid fuels warrants its careful consideration as a material of construction. Internal aluminum components (such as bubble trays and caps) of many oil refinery vessels have been giving satisfactory service for some time.

Considerable interest is being shown in the use of aluminum piping for oil and gas transmission for varying service conditions and pressures up to 1000 pounds per square inch. Wrought fittings are available for such service.

With both pipe and fittings fabricated from the same high-strength material, the piping engineer can take fuller advantage of the increased mechanical properties offered by the heat-treatable aluminum alloys.

Low Temperature Applications: In the synthesis of gasoline from natural gas, as in many other operations in the various chemical fields, large quantities of liquid oxygen must be employed. Because the temperature involved is −300 °F, aluminum is used in the fabrication of pressure vessels, heat exchangers and piping for handling this liquid.

Irrigation: The light weight of aluminum has led to its wide use in irrigation piping in the South, Southwest and Northwest. Since this piping has a combination of mechanical and welded joints, it is readily portable and can be moved from location to location with a minimum amount of labor expended.

Plumbing; Drainage Piping: The use of aluminum soil pipe for above-ground drainage systems is gaining in popularity due to its workability and light weight. Although aluminum pipe is not recommended for drains carrying alkaline liquids, it may be suitable if used with a chemical protective coating to resist acid and alkaline attack. The following technical data can be used as a guide in determining applications for aluminum soil pipe:

—Minimum tensile strength: 27,000 pounds per square inch.
—Minimum hydrostatic pressure: 150 pounds.
—Completely resistant to sulphuric gases.
—A 5-foot length of pipe weighs only 13 pounds.
—Completely interchangeable with extra heavy cast-iron pipe and fittings.
—Will not rust or scale.

TABLE 8-3: WROUGHT ALUMINUM AND ALUMINUM ALLOY[1] PIPE, TUBING, BUTT WELDING FITTINGS AND FLANGES[2]

ITEM	SIZE RANGE INCHES	THICKNESS RANGE
Seamless Pipe (IPS OD)		
Cold Drawn	1/8–12	Std. & E. H.
Extruded	1/2–12	Std. & E. H.
Seamless Tubing (Nom. OD)		
Cold Drawn	1/8–12	0.010 in.–0.500 in.
Extruded	1 1/4–12	0.063 in.–1.500 in.
Seamless Butt Welding Fittings		
90-deg Ells, Long Radius	3/4–14	Std. & E. H.
45-deg Ells, Long Radius	3/4–14	Std. & E. H.
180-deg Returns, Long Radius	3/4–14	Std. & E. H.
90-deg Ells, Short Radius	1–16	Std.
90-deg Ells, Short Radius	1 1/2–16	E. H.
180-deg Returns, Short Radius	1–16	Std.
180-deg Returns, Short Radius	1 1/2–16	E. H.
Tees, Straight and Reducing[3]	3/4–8	Std.
Tees, Straight and Reducing[3]	3/4–5	E. H.
Reducers, Concentric and Eccentric	3/4–10	Std. & E. H.
Lap Joint Stubs	3/4–10	Std. & E. H.
Caps	1–24	Std. & E. H.
Crosses[3]	3/4–8	Std.
Crosses[3]	3/4–5	E. H.
Welding Flanges		
Welding Neck	Refer to maker	

Notes:
[1] The pipe, tubing and fittings listed in this table are regularly available in alloy 3003. Pipe and tubing are also regularly available in alloys 1100, 6061 and 6063 in various hardnesses or temper. Fittings of these materials are also available on special order. Flanges are furnished only in alloy 6053.
[2] Fittings are regularly made to IPS dimensions. Fittings to match tubing dimensions are available on special order. Fittings grooved for special couplings are also available on special order.
[3] Tees and crosses drawn from fusion welded pipe can be obtained in sizes up to 18 inches on special order.

TABLE 8-4: CAST ALUMINUM ALLOY[1] SCREWED FITTINGS AND FLANGES, 125 PSI[2]

ITEM	SIZE RANGE INCHES
90-deg Elbows	1/8–6
90-deg Elbows, Reducing	1/4–2
45-deg Elbows	1/8–5
90-deg Street Elbows	1/8–6
90-deg Street Elbows, Reducing	1/2–4
45-deg Street Elbows	1/2–2
180-deg Close Returns	3/8–4
180-deg Open Returns	3/8–4
Tees, Straight	1/8–6
Tees, Reducing	1/4–2
Y's, Straight	1/2–5
Crosses, Straight	1/8–4
Reducers	1/8–6
Plugs, Square Head	1/8–6
Bushings	1/8–6
Caps	1/8–6
Couplings (Std. and Extra Heavy)	1/8–6
Unions	1/4–2
Locknuts	1/8–4
Nipples[3]	1/8–4

Notes:
[1] The fittings listed are regularly available in Alloy B214. Fittings cast in other alloys may be obtained on special order.
[2] These fittings are air tested at 60 psi. They are rated at 125 psi working pressure at 150 °F. For adjusted pressure-temperature ratings at higher temperatures, consult the manufacturers. These fittings meet U. S. Navy specification 45F11.
[3] These nipples are made from the wrought aluminum materials.

Water Piping: With certain limitations, aluminum piping with its savings in weight and cost can perform as well as copper and steel for many water supply systems. In the new Alcoa building in Pittsburgh about 60 percent of all piping used is aluminum. As a result, the builders estimate that aluminum can save 25 percent of the piping costs in similar office buildings.

Aluminum pipe for use in water systems offers less resistance to the flow of water than does steel

TABLE 8-5: CAST ALUMINUM ALLOY[1] FLANGED FITTINGS AND FLANGES, 125 PSI[2]

ITEM	SIZE RANGE INCHES
90-deg Elbows	1–8
90-deg Long Sweep Elbows	1–8
90-deg Side Outlet Elbows	1–8
45-deg Elbows	1–8
Tees	1–8
Tees, Single Sweep	1–8
Tees, Double Sweep	1–8
Tees, Side Outlet	1–8
Crosses	1–8
Laterals	1–8
Y's	1–8
Reducers	1–8
Flanges, Screwed	1–8
Flanges, Blind	1–8

Notes:
[1] The fittings listed are regularly available in Alloy B214. Fittings cast in other alloys may be obtained on special order.
[2] These fittings and flanges conform to the dimensions of 150 lb cast steel flanged fittings and flanges (See ASA Standard B16e). They are air tested at 60 psi and are rated at 125 psi working pressure at 150 °F. For adjusted pressure-temperature ratings at higher temperatures, consult the manufacturers.

of the same internal diameter due to lower friction loss. Table 8-6 gives the loss of head in feet per 100 feet for flow of water in aluminum piping. Table 8-7 provides data on dimensions and weights.

When using aluminum for water piping, it is necessary to provide for protection against electrolytic corrosion, since at the present time all plumbing fixtures come with copper fittings.

This problem can be solved by terminating the aluminum pipes at the flanged water valves before the fixtures. At the valved connection, electrolytic corrosion can be prevented by using special nonconductive gaskets between flanges and around bolts, thus barring the electrolytic current from flowing across the joint. Although these joints seem complicated, they cost about the same as copper-to-copper joints, and the need for them will dis-

TABLE 8-6: LOSS OF HEAD IN FEET PER HUNDRED FEET FOR FLOW OF WATER IN ALUMINUM PIPING (Continued on Page 308)

FLOW		NOMINAL PIPE SIZE, INCH								
GALLONS PER MINUTE	CUBIC FEET PER SECOND	1/8	1/4	3/8	1/2	3/4	1	1¼	1½	2
1/8	.0003	1.76	0.43	......	......	......	......	......	......	......
1/4	.0006	6.00	1.42	......	......	......	......	......	......	......
3/8	.0008	12.2	2.91	......	......	......	......	......	......	......
1/2	.0011	20.4	4.84	1.13	......	......	......	......	......	......
5/8	.0014	30.3	7.18	1.69	......	......	......	......	......	......
3/4	.0017	41.9	9.91	2.34	......	......	......	......	......	......
7/8	.0019	55.1	13.0	3.06	......	......	......	......	......	......
1	.0022	69.5	16.5	3.88	1.28	.34	.11	......	......	......
1¼	.0028	104	24.4	5.74	1.89	.50	.16	......	......	......
1½	.0033	142	33.6	7.94	2.62	.69	.22	......	......	......
1¾	.0039	187	44.1	10.5	3.45	.90	.28	......	......	......
2	.0045	238	56.1	13.3	4.36	1.14	.36	.10	......	......
2½	.0056	351	83.3	19.6	6.47	1.70	.53	.15	......	......
3	.0067	487	115	27.1	8.94	2.34	.74	.20	.10	......
3½	.0078	......	151	35.5	11.7	3.07	.96	.26	.13	......
4	.0089	......	191	45.1	14.9	3.88	1.23	.33	.16	......
4½	.010	......	237	57.5	18.3	4.77	1.51	.41	.20	......
5	.011	......	285	66.9	22.1	5.78	1.82	.49	.23	.07
6	.013	......	......	92.4	30.0	7.96	2.50	.68	.33	.10
7	.016	......	......	121	39.9	10.5	3.29	.90	.43	.13
8	.018	2½	3	153	50.5	13.3	4.17	1.13	.54	.16
9	.020	......	......	......	62.3	16.3	5.14	1.39	.67	.20
10	.022	.11	.04		75.1	19.6	6.20	1.68	.77	.24
15	.033	.21	.08	3½	......	40.0	12.7	3.44	1.65	.50
20	.045	.36	.13	.06	......	67.0	21.1	5.71	2.75	.83
25	.056	.53	.19	.09	......	......	31.2	8.50	4.06	1.24
30	.067	.73	.26	.13		......	43.0	11.7	5.59	1.70
35	.078	.96	.34	.17	4	......	56.8	15.4	7.32	2.24
40	.089	1.22	.43	.22	.12		71.9	19.5	9.35	2.48
45	.10	1.50	.53	.27	.15	5	......	23.9	11.5	3.49
50	.11	1.81	.64	.32	.18	......	......	28.8	13.8	4.20
60	.13	2.49	.89	.45	.24	.08	......	39.7	19.2	5.78

TABLE 8-6: LOSS OF HEAD IN FEET PER HUNDRED FEET FOR FLOW OF WATER IN ALUMINUM PIPING (Continued)

FLOW		NOMINAL PIPE SIZE, INCH								
GALLONS PER MINUTE	CUBIC FEET PER SECOND	1/8	1/4	3/8	1/2	3/4	1	1¼	1½	2
70	.16	3.26	1.16	.58	.32	.11		52.3	25.1	7.64
80	.18	4.12	1.47	.73	.40	.14	6	65.9	31.8	9.64
90	.20	5.09	1.81	.91	.49	.17		......	39.4	11.9
100	.22	6.14	2.18	1.08	.60	.20	.09	......	47.1	14.3
120	.27	8.50	3.02	1.51	.83	.28	.12	......	65.0	19.7
140	.31	11.1	3.95	1.97	1.08	.37	.15		85.7	26.0
160	.36	14.2	4.99	2.49	1.37	.47	.19	8	......	32.7
180	.40	17.3	6.15	3.08	1.68	.57	.24	(.322)	......	......
200	.45	20.9	7.41	3.70	2.04	.69	.29	.08	......	......
220	.49	24.6	8.75	4.39	2.40	.82	.34	.09	......	......
240	.53	28.7	10.2	5.14	2.81	.96	.40	.11	10	......
260	.58	33.2	11.8	5.92	3.24	1.10	.47	.12	(.365)	......
280	.62	37.7	13.5	6.72	3.66	1.25	.52	.14	......	......
300	.67	42.7	15.2	7.62	4.13	1.41	.58	.16	.05	
350	.78	......	20.0	9.95	5.48	1.86	.78	.21	.07	12
400	.89	......	25.4	12.7	6.92	2.35	.98	.27	.09	(.375)
450	1.00	......	31.8	15.6	8.50	2.88	1.20	.33	.11	......
500	1.11	......	38.6	19.0	10.3	3.49	1.45	.39	.13	.06
550	1.23	......	......	22.8	12.3	4.13	1.72	.47	.16	.07
600	1.34	......	......	26.8	14.4	4.82	2.00	.54	.18	.08
650	1.45	......	......	31.1	16.7	5.56	2.31	.63	.21	.09
700	1.56	......	......	35.8	19.3	6.41	2.64	.72	.24	.10
750	1.67	......	......	......	22.2	7.25	2.99	.81	.27	.12
800	1.78	......	......	......	24.8	8.19	3.35	.90	.30	.13
850	1.89	......	......	......	27.8	9.19	3.75	1.00	.34	.14
900	2.01	......	......	......	31.2	10.2	4.17	1.11	.37	.16
950	2.12	......	......	......	34.2	11.3	4.61	1.22	.41	.17
1,000	2.23	......	......	......	37.6	12.5	5.08	1.35	.45	.19
1,100	2.45	......	......	......	......	14.9	6.10	1.60	.53	.23
1,200	2.67	......	......	......	......	17.5	7.22	1.87	.62	.26
1,300	2.90	......	......	......	......	20.4	8.40	2.20	.72	.30
1,400	3.12	......	......	......	......	23.4	9.65	2.52	.83	.35

TABLE 8-6: LOSS OF HEAD IN FEET PER HUNDRED FEET FOR FLOW OF WATER IN ALUMINUM PIPING (Concluded)

FLOW		NOMINAL PIPE SIZE, INCH								
GALLONS PER MINUTE	CUBIC FEET PER SECOND	1/8	1/4	3/8	1/2	3/4	1	1 1/4	1 1/2	2
1,500	3.34	......	......	......	......	26.7	10.9	2.88	.94	.40
1,600	3.56	......	......	......	......	30.1	12.3	3.24	1.07	.44
1,700	3.79	......	......	......	......	33.7	13.8	3.64	1.19	.49
1,800	4.01	......	......	......	......	37.6	15.4	4.05	1.33	.55
1,900	4.23	......	......	......	......	41.5	17.0	4.47	1.46	.61
2,000	4.46	......	......	......	......	45.6	18.7	4.92	1.61	.67
2,200	4.90	......	......	......	......	......	22.4	5.85	1.93	.81
2,400	5.35	......	......	......	......	......	26.2	6.88	2.27	.95
2,600	5.79	......	......	......	......	......	30.2	8.00	2.64	1.08
2,800	6.24	......	......	......	......	......	......	9.16	3.04	1.26
3,000	6.68	......	......	......	......	......	......	10.5	3.46	1.44
3,500	7.80	......	......	......	......	......	......	13.9	4.64	1.93
4,000	8.91	......	......	......	......	......	......	17.8	5.91	2.46
4,500	10.03	......	......	......	......	......	......	22.2	7.36	3.06
5,000	11.14	......	......	......	......	......	......	27.1	8.92	3.72
5,500	12.26	......	......	......	......	......	......	32.5	10.7	4.47
6,000	13.37	......	......	......	......	......	......	38.0	12.6	5.22
7,000	15.60	......	......	......	......	......	......	......	16.7	7.00
8,000	17.83	......	......	......	......	......	......	......	21.3	8.95
9,000	20.05	......	......	......	......	......	......	......	26.6	11.1
10,000	22.28	......	......	......	......	......	......	......	32.2	13.5
12,500	27.85	......	......	......	......	......	......	......	......	20.3
15,000	33.42	......	......	......	......	......	......	......	......	28.7
17,500	39.00	......	......	......	......	......	......	......	......	38.3

Computed for new pipe, exclusive of losses at joints, valves, etc.
Temperature of water 75°F.

appear in a completely aluminum plumbing system which would be free of electrolytic action.

Another method of protection is the application of sacrificial pipes as discussed in Section 2.4 (Protective Measures Against Corrosion).

Aluminum piping is seldom specified for carrying steam or waste or high water pressures because steam condensate is sometimes laden with salt compounds which may attack the metal; caustic compounds presently used for cleaning waste lines may corrode aluminum; large water risers demand thick-walled pipes, uneconomical in aluminum.

PRECAUTIONARY MEASURES: Experience as well as field and laboratory tests have shown that, in addition to precautions against galvanic corro-

TABLE 8-7: DIMENSIONS AND WEIGHTS OF ALUMINUM PIPING

NOMINAL PIPE SIZE INCHES	SCHEDULE NUMBER[1]	OUTSIDE DIAMETER INCHES	INSIDE DIAMETER INCHES	WALL THICKNESS INCH	WEIGHT PER LINEAR FOOT POUNDS PLAIN ENDS[2]	CROSS-SECTIONAL WALL AREA SQUARE INCHES	INSIDE CROSS-SECTIONAL AREA SQUARE INCHES	MOMENT OF INERTIA INCHES^4	SECTION MODULUS INCHES^3	RADIUS OF GYRATION INCHES
1/8	40[3]	0.405	0.269	0.068	0.085	0.0720	0.0568	0.0011	0.0053	0.1215
	80[4]	0.405	0.215	0.095	0.109	0.0925	0.0363	0.0012	0.0060	0.1146
1/4	40[3]	0.540	0.364	0.088	0.147	0.1250	0.1041	0.0033	0.0123	0.1628
	80[4]	0.540	0.302	0.119	0.185	0.1574	0.0716	0.0038	0.0139	0.1547
3/8	40[3]	0.675	0.493	0.091	0.196	0.1670	0.1909	0.0073	0.0216	0.2090
	80[4]	0.675	0.423	0.126	0.256	0.2173	0.1405	0.0086	0.0255	0.1991
1/2	40[3]	0.840	0.622	0.109	0.294	0.2503	0.3039	0.0171	0.0407	0.2613
	80[4]	0.840	0.546	0.147	0.376	0.3200	0.2341	0.0201	0.0478	0.2505
3/4	10	1.050	0.884	0.083	0.297	0.2521	0.6138	0.0297	0.0566	0.3432
	40[3]	1.050	0.824	0.113	0.391	0.3326	0.5333	0.0370	0.0705	0.3337
	80[4]	1.050	0.742	0.154	0.510	0.4335	0.4324	0.0448	0.0853	0.3214
1	5	1.315	1.185	0.065	0.300	0.2553	1.103	0.0500	0.0760	0.4425
	10	1.315	1.097	0.109	0.486	0.4130	0.9452	0.0757	0.1151	0.4282
	40[3]	1.315	1.049	0.133	0.581	0.4939	0.8643	0.0873	0.1328	0.4205
	80[4]	1.315	0.957	0.179	0.751	0.6388	0.7193	0.1056	0.1606	0.4066
1 1/4	5	1.660	1.530	0.065	0.383	0.3257	1.839	0.1037	0.1250	0.5644
	10	1.660	1.442	0.109	0.625	0.5311	1.633	0.1605	0.1934	0.5497
	40[3]	1.660	1.380	0.140	0.786	0.6685	1.496	0.1947	0.2346	0.5397
	80[4]	1.660	1.278	0.191	1.037	0.8815	1.283	0.2418	0.2913	0.5238
1 1/2	5	1.900	1.770	0.065	0.441	0.3747	2.461	0.1579	0.1662	0.6492
	10	1.900	1.682	0.109	0.721	0.6133	2.222	0.2468	0.2598	0.6344
	40[3]	1.900	1.610	0.145	0.940	0.7995	2.036	0.3099	0.3262	0.6226
	80[4]	1.900	1.500	0.200	1.256	1.068	1.767	0.3912	0.4118	0.6052
2	5	2.375	2.245	0.065	0.555	0.4717	3.958	0.3149	0.2652	0.8170
	10	2.375	2.157	0.109	0.913	0.7760	3.654	0.4992	0.4204	0.8021
	40[3]	2.375	2.067	0.154	1.264	1.074	3.356	0.6657	0.5606	0.7871
	80[4]	2.375	1.939	0.218	1.737	1.477	2.953	0.8679	0.7309	0.7665
2 1/2	5	2.875	2.709	0.083	0.856	0.7280	5.764	0.7100	0.4939	0.9876
	10	2.875	2.635	0.120	1.221	1.039	5.453	0.9873	0.6868	0.9750
	40[3]	2.875	2.469	0.203	2.004	1.704	4.788	1.530	1.064	0.9474
	80[4]	2.875	2.323	0.276	2.650	2.254	4.238	1.924	1.339	0.9241
3	5	3.500	3.334	0.083	1.048	0.8910	8.730	1.301	0.7435	1.208

TABLE 8-7: DIMENSIONS AND WEIGHTS OF ALUMINUM PIPING (Concluded)

NOMINAL PIPE SIZE INCHES	SCHEDULE NUMBER[1]	OUTSIDE DIAMETER INCHES	INSIDE DIAMETER INCHES	WALL THICKNESS INCH	WEIGHT PER LINEAR FOOT POUNDS PLAIN ENDS[2]	CROSS-SECTIONAL WALL AREA SQUARE INCHES	INSIDE CROSS-SECTIONAL AREA SQUARE INCHES	MOMENT OF INERTIA INCHES[4]	SECTION MODULUS INCHES[3]	RADIUS OF GYRATION INCHES
	10	3.500	3.260	0.120	1.498	1.274	8.346	1.822	1.041	1.196
	40[3]	3.500	3.068	0.216	2.621	2.228	7.393	3.017	1.724	1.164
	80[4]	3.500	2.900	0.300	3.547	3.016	6.605	3.894	2.225	1.136
3½	5	4.000	3.834	0.083	1.201	1.021	11.55	1.960	0.9799	1.385
	10	4.000	3.760	0.120	1.720	1.463	11.10	2.755	1.378	1.372
	40[3]	4.000	3.548	0.226	3.151	2.680	9.887	4.788	2.394	1.337
	80[4]	4.000	3.364	0.318	4.326	3.678	8.888	6.281	3.140	1.307
4	5	4.500	4.334	0.083	1.354	1.152	14.75	2.810	1.249	1.562
	10	4.500	4.260	0.120	1.942	1.651	14.25	3.963	1.761	1.549
	40[3]	4.500	4.026	0.237	3.733	3.174	12.73	7.232	3.214	1.510
	80[4]	4.500	3.826	0.337	5.183	4.407	11.50	9.611	4.272	1.477
5	40[3]	5.563	5.047	0.258	5.057	4.300	20.01	15.16	5.451	1.878
	80[4]	5.563	4.813	0.375	7.188	6.112	18.19	20.67	7.432	1.839
6	40[3]	6.625	6.065	0.280	6.564	5.581	28.89	28.14	8.496	2.246
	80[4]	6.625	5.761	0.432	9.884	8.405	26.07	40.49	12.22	2.195
8	30	8.625	8.071	0.277	8.543	7.265	51.16	63.35	14.69	2.953
	40[3]	8.625	7.981	0.322	9.878	8.399	50.03	72.49	16.81	2.938
	80[4]	8.625	7.625	0.500	15.01	12.76	45.66	105.7	24.51	2.878
10	..	10.750	10.192	0.279	10.79	9.178	81.59	125.9	23.42	3.704
	30	10.750	10.136	0.307	11.84	10.07	80.69	137.4	25.57	3.694
	40[3]	10.750	10.020	0.365	14.00	11.91	78.85	160.7	29.90	3.674
	80[4]	10.750	9.750	0.500	18.93	16.10	74.66	211.9	39.43	3.628
12	30	12.750	12.090	0.330	15.14	12.88	114.8	248.5	38.97	4.393
	..[3]	12.750	12.000	0.375	17.14	14.58	113.1	279.3	43.81	4.377
	..[4]	12.750	11.750	0.500	22.63	19.24	108.4	361.5	56.71	4.335

[1] Schedule Numbers conform to American Standard for Wrought Iron and Wrought Steel Pipe, ASA B36.10.
[2] Weights calculated for 6061 and 6063. For 3003 multiply by 1.010.
[3] Also designated as Extra-heavy or Extra-strong Pipe. All calculations based on nominal dimensions.
[4] Also designated as Standard Pipe.

sion (see Section 2.4) in general, the following specific precautions must be observed in designing aluminum piping systems:

Pipe Anchors, Hangers and Supports: Where possible, anchors, hangers and supports should be made of aluminum. If steel or cast iron is employed for these members, the surfaces that contact the aluminum should be galvanized or cadmium plated as a protection against galvanic corrosion.

Insulation: Dry thermal insulation is satisfactory. However, if the piping is moist or collects condensate, boro-silicate glass fiber should be employed.

Painting the aluminum piping is also recommended.

Gaskets: Those materials which do not readily absorb moisture are best suited for use with aluminum alloys. Synthetic resins, synthetic rubbers, cloth or paper impregnated with bituminous products, and rubber-base compounds are most suitable.

Cleaning: When corrosive action is evident on aluminum piping systems, the lines should be cleaned with a wire brush and washed with hot solutions of Oakite No. 33 or 36, Dioxine 526, Kilite Process K, or Turco WD-1. The pipe should then be rinsed with cold water and air dried.

Painting: If aluminum pipe is to be buried in the ground, it should be protected thoroughly by a suitable bituminous coating or wrapping similar to that used for steel pipe.

Pipes can be painted inside and out with such paints as carbozite, zinc chromate primer, or zincilate (see Section 2.4).

Flexibility: The coefficient of thermal expansion of aluminum is approximately twice that of steel. This should be taken into consideration by providing sufficient clearances in aluminum piping systems. Because of the low modulus of elasticity, however, thermal stresses in aluminum pipes are no greater than they are in steel. Due to high thermal conductivity, temperature stresses may be lower in some applications.

INSTALLATION:

Bending: Aluminum pipe and tube can be formed either cold or hot, following procedures similar to those employed when bending ferrous materials. In view of the wide varieties of tempers available, the supplier of the pipe should be advised of specific bending requirements (see Section 3.5).

Cutting: No difficulty should be experienced when the normal hacksaw practice is followed. A cutting lubricant of kerosene and lard oil is quite satisfactory. When machine cutting, the best results will be obtained by using fine to medium feeds and comparatively high speeds (see Section 3.5).

Threading: When threading aluminum, a lubricant of zinc dust and vaseline, or a heavy cup grease containing about 25 percent lubricating graphite, should be used (see Section 3.5).

Welding: (See Section 4.2). The following processes are usually employed in welding aluminum piping installations:

Inert Gas-Shielded Arc Welding Using Argon appears to be the most suitable method for the various requirements of pipe welding. An arc is struck between a tungsten electrode and the base metal, and an inert gas (argon) is used as a protective covering for the weld and filler metal. Alternating current welding is used with high frequency power superimposed on the welding circuit. In this method no flux is necessary. High purity (99.8 percent or better) welding grade argon must be used.

Where the thickness of the metal is 1/16-inch or more, the ends to be welded should be spaced from 1/16 to 1/8-inch apart. Square ends do not have to be separated for satisfactory results where the metal is less than 1/16-inch in thickness, but the standard 37½ degree bevel should be used on thicker material. The equipment required in addition to the standard a.c. welding generator includes an argon tank, special hose, a special electrode holder, a source of cooling water, a high frequency stabilizer, a regulator and a flowmeter.

The welds produced by this method are of acceptable quality. Worthwhile advantages stem from two facts: No flux is necessary, and all-position welding is possible.

Oxyhydrogen and Oxyacetylene Welding: Some pipe fabricators express a preference for the oxyhydrogen welding method. Welding qualifications, including the back and face bends and elongation tests required by the ASME code, have been met by this method.

The comments already made on joint preparation also apply to gas welding. In the oxyhydrogen and oxyacetylene methods, aluminum flux is used on both the material to be welded and the rod. Complete removal of the flux is mandatory. This is done immediately after welding by washing both the inside and outside with hot water. Preheating from 500 to 700 °F is desirable on heavy sections. Temperature indicating equipment is preferable for control. A neutral or slightly reducing flame is recommended. A neutral flame is indicated by a well-defined blue cone near the torch tip.

Fittings and Flanges: Tables 8-3, 8-4 and 8-5 show the sizes and types of fittings and flanges available for aluminum piping systems.

Valves: Aluminum body valves are available in sizes ½ through 8 inches for 150 pounds service for use on water lines. OS&Y victulic end gate valves designed for use on light hydrocarbon service have proven themselves over a long period of time for pressures up to 200 pounds per square inch.

8.2 ALUMINUM DUCT SYSTEMS FOR HEATING, VENTILATING AND AIR CONDITIONING

The purpose of this section is to treat those physical properties of aluminum which have a direct bearing on ducts, and to discuss the design and construction of duct systems.

Basic physical and mechanical properties treated in Chapter 2 should aid the designer in making the best selection of aluminum for these systems.

Physical Properties of Aluminum as Utilized in Duct Systems:

Appearance and Durability: Original finish of aluminum is maintained without cleaning or painting. The metal is not subject to rusting or corrosion from condensation when handling cooled air.

Emissivity: Due to low emissivity, aluminum ducts have less heat gain (in cooling systems) and heat loss (in heating systems) than do conventional galvanized steel ducts, black steel ducts or asbestos-paper-covered ducts of the same size and shape. Thus, by reducing the heat-transfer loss through the duct wall, the actual quantity of air to be delivered to the conditioned space can be reduced with a corresponding decrease in duct size.

Thermal Expansion: The average coefficient of linear expansion for aluminum is 13 x 10^{-6} per degree Fahrenheit (68–212 °F). (See Table 2-4.) Particular consideration must be given to the effect of expansion and contraction when using aluminum.

Non-Sparking: Aluminum is generally non-sparking and can therefore be used in certain hazardous locations where an accidental spark might cause an explosion or a fire.

Weight: The light weight of the aluminum results in great savings in cost during shipping, fabrication and erection. Aluminum has a specific gravity of about 2.7 as compared to 7.9 for steel and 8.9 for copper.

Friction Losses: In laying out aluminum duct systems, the designer may employ the same procedures used for galvanized steel ducts. The figures in the "Guide" of the American Society of Heating and Ventilating Engineers are based on standard air of .075-pound per cubic foot density flowing through average, clean, round, galvanized metal ducts having approximately 40 joints per 100 feet. The figures for determining friction losses in aluminum ducts are in the same form as those in the "Guide". Figure 8-1 gives friction loss per 100 feet in aluminum duct as a function of velocity, volume and diameter. Figure 8-2 is similar to Figure 8-1, but is for larger size ducts.

By use of a few typical examples of duct selection, the difference between aluminum duct and galvanized steel duct can clearly be illustrated:

Example 1: Given 2000 CFM, 100-foot duct, allowable friction loss of .10. Determine aluminum duct size and velocity and galvanized steel duct size and velocity. From Figure 8-1, select 18-inch diameter aluminum duct at a velocity of 1150 feet per minute.

From ASHVE Guide, select 18-inch diameter galvanized steel duct at a velocity of 1150 feet per minute.

Example 2: Given 200 CFM, 1500 feet per minute maximum allowable velocity. Determine aluminum duct size and friction loss, and galvanized steel duct size and friction loss.

From Figure 8-1, select 5-inch diameter aluminum duct at .75-inch of water per 100 feet.

From ASHVE Guide, select 5-inch diameter galvanized steel duct at .80-inch of water per 100 feet.

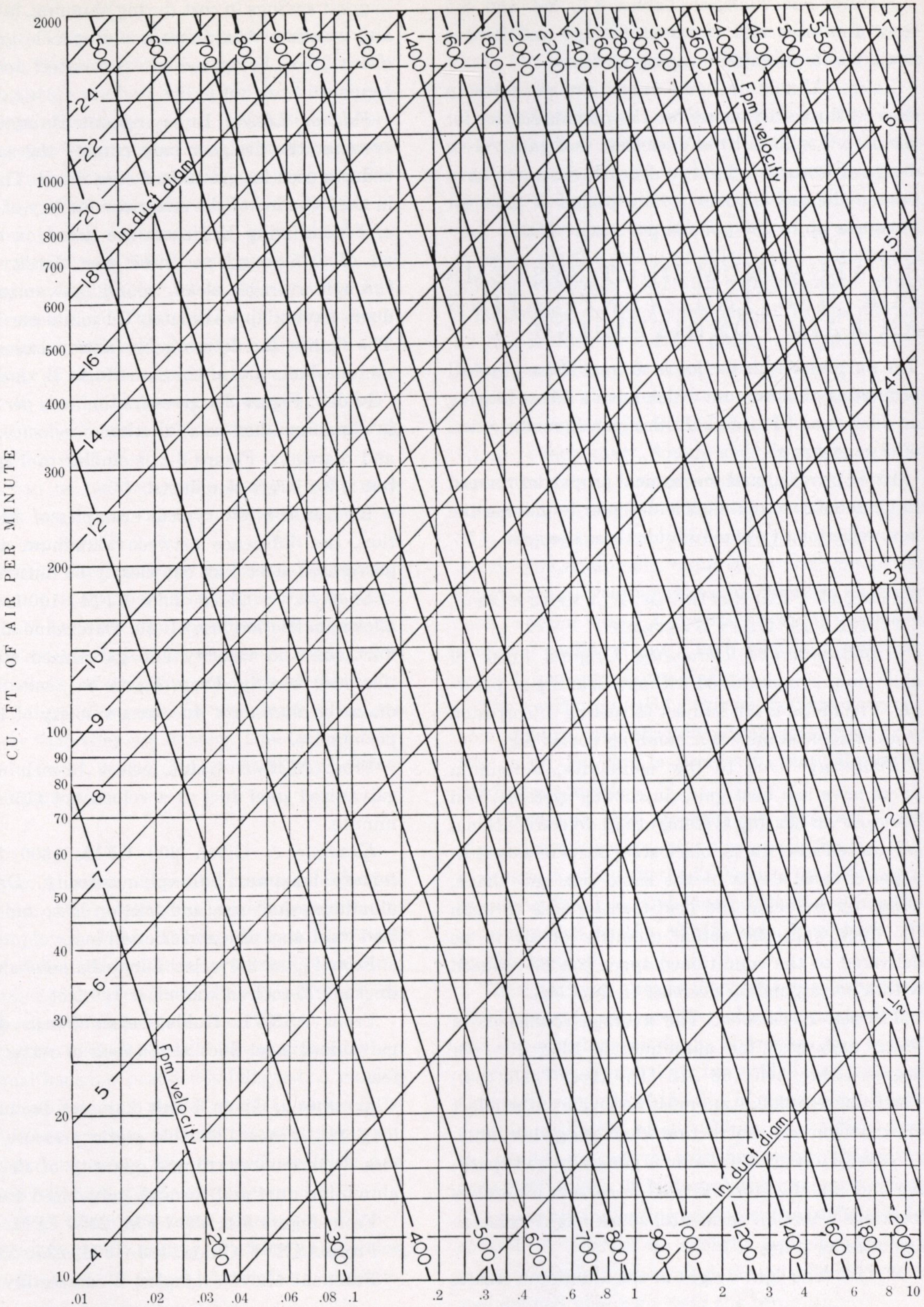
Example 3: Given 6-inch diameter duct, 100 feet long 1½ inches allowable static pressure friction loss. Determine maximum quantity of air through aluminum duct and through galvanized steel duct.

From Figure 8-1: 500 CFM, 2500 FPM.

From ASHVE Guide: 460 CFM, 2350 FPM.

From the above examples, it can readily be seen

Figure 8-1. Friction loss in inches of water per 100 feet. (From "The Design of Aluminum Duct Systems" by F. W. Hutchinson, Kaiser Aluminum & Chemical Sales, Inc. 1954.)



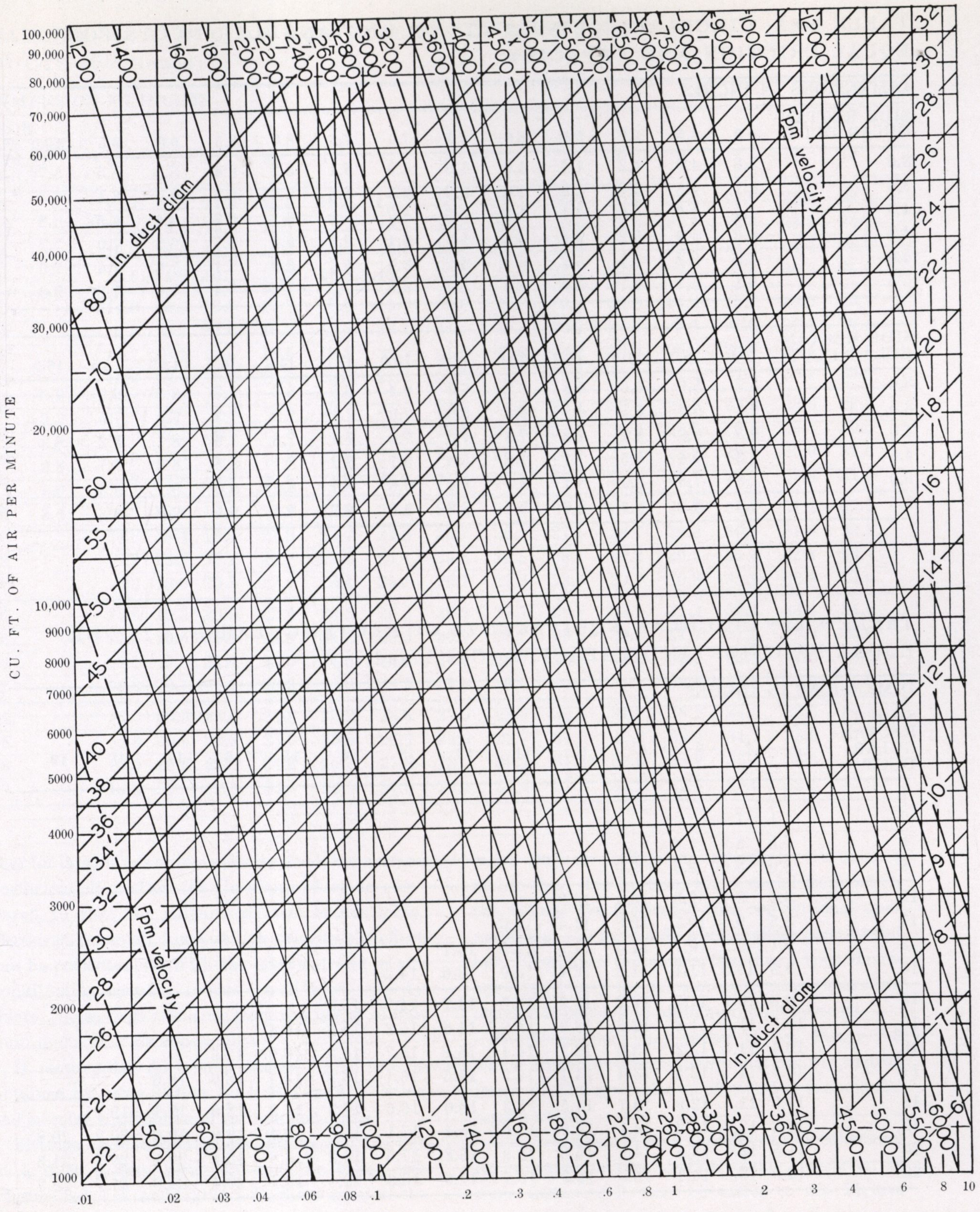


Figure 8-2. Friction loss in inches of water per 100 feet. (From Hutchinson).

TABLE 8-8A: CIRCULAR EQUIVALENTS OF RECTANGULAR DUCTS FOR EQUAL FRICTION AND CAPACITY

DIMENSIONS IN INCHES

SIDE RECTANGULAR DUCT	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0
3.0	3.8	4.0	4.2	4.4	4.6	4.8	4.9	5.1	5.2	5.4	5.5	5.6	5.7
3.5	4.1	4.3	4.6	4.8	5.0	5.2	5.3	5.5	5.7	5.8	6.0	6.1	6.3
4.0	4.4	4.6	4.9	5.1	5.3	5.5	5.7	5.9	6.1	6.3	6.4	6.6	6.8
4.5	4.6	4.9	5.2	5.4	5.6	5.9	6.1	6.3	6.5	6.7	6.9	7.0	7.2
5.0	4.9	5.2	5.5	5.7	6.0	6.2	6.4	6.7	6.9	7.1	7.3	7.4	7.6
5.5	5.1	5.4	5.7	6.0	6.3	6.5	6.8	7.0	7.2	7.4	7.6	7.8	8.0

SIDE RECTANGULAR DUCT	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0	15.5	16.0
3.0	5.7	5.9	6.0	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.8	6.9	7.0
3.5	6.3	6.4	6.5	6.7	6.8	6.9	7.0	7.1	7.2	7.3	7.4	7.5	7.6
4.0	6.8	6.9	7.1	7.2	7.3	7.5	7.6	7.7	7.8	7.9	8.1	8.2	8.3
4.5	7.2	7.4	7.5	7.7	7.8	8.0	8.1	8.2	8.4	8.5	8.6	8.7	8.9
5.0	7.6	7.8	8.0	8.1	8.3	8.4	8.6	8.7	8.9	9.0	9.1	9.3	9.4
5.5	8.0	8.2	8.4	8.6	8.7	8.8	9.0	9.2	9.4	9.5	9.6	9.8	9.8

TABLE 8-8B; CIRCULAR EQUIVALENTS OF RECTANGULAR DUCTS FOR EQUAL FRICTION AND CAPACITY (Continued)

DIMENSIONS IN INCHES

SIDE RECTANGULAR DUCT	6	7	8	9	10	11	12	13	14	15	16	17	18	19
6	6.6													
7	7.1	7.7												
8	7.5	8.2	8.8											
9	8.0	8.6	9.3	9.9										
10	8.4	9.1	9.8	10.4	10.9									
11	8.8	9.5	10.2	10.8	11.4	12.0								
12	9.1	9.9	10.7	11.3	11.9	12.5	13.1							
13	9.5	10.3	11.1	11.8	12.4	13.0	13.6	14.2						
14	9.8	10.7	11.5	12.2	12.9	13.5	14.2	14.7	15.3					
15	10.1	11.0	11.8	12.6	13.3	14.0	14.6	15.3	15.8	16.4				
16	10.4	11.4	12.2	13.0	13.7	14.4	15.1	15.7	16.3	16.9	17.5			
17	10.7	11.7	12.5	13.4	14.1	14.9	15.5	16.1	16.8	17.4	18.0	18.6		
18	11.0	11.9	12.9	13.7	14.5	15.3	16.0	16.6	17.3	17.9	18.5	19.1	19.7	
19	11.2	12.2	13.2	14.1	14.9	15.6	16.4	17.1	17.8	18.4	19.0	19.6	20.2	20.8
20	11.5	12.5	13.5	14.4	15.2	15.9	16.8	17.5	18.2	18.8	19.5	20.1	20.7	21.3
22	12.0	13.1	14.1	15.0	15.9	16.7	17.6	18.3	19.1	19.7	20.4	21.0	21.7	22.3

TABLE 8-8C; CIRCULAR EQUIVALENTS OF RECTANGULAR DUCTS (Continued)

DIMENSION IN INCHES														
SIDE RECTANGULAR DUCT	6	7	8	9	10	11	12	13	14	15	16	17	18	19
24	12.4	13.6	14.6	15.6	16.6	17.5	18.3	19.1	19.8	20.6	21.3	21.9	22.6	23.2
26	12.8	14.1	15.2	16.2	17.2	18.1	19.0	19.8	20.6	21.4	22.1	22.8	23.5	24.1
28	13.2	14.5	15.6	16.7	17.7	18.7	19.6	20.5	21.3	22.1	22.9	23.6	24.4	25.0
30	13.6	14.9	16.1	17.2	18.3	19.3	20.2	21.1	22.0	22.9	23.7	24.4	25.2	25.9
32	14.0	15.3	16.5	17.7	18.8	19.8	20.8	21.8	22.7	23.6	24.4	25.2	26.0	26.7
34	14.4	15.7	17.0	18.2	19.3	20.4	21.4	22.4	23.3	24.2	25.1	25.9	26.7	27.5
36	14.7	16.1	17.4	18.6	19.8	20.9	21.9	23.0	23.9	24.8	25.8	26.6	27.4	28.3
38	15.0	16.4	17.8	19.0	20.3	21.4	22.5	23.5	24.5	25.4	26.4	27.3	28.1	29.0
40	15.3	16.8	18.2	19.4	20.7	21.9	23.0	24.0	25.1	26.0	27.0	27.9	28.8	29.7
42	15.6	17.1	18.5	19.8	21.1	22.3	23.4	24.5	25.6	26.6	27.6	28.5	29.4	30.4
44	15.9	17.5	18.9	20.2	21.5	22.7	23.9	25.0	26.1	27.2	28.2	29.1	30.0	31.0
46	16.2	17.8	19.2	20.6	21.9	23.2	24.3	25.5	26.7	27.7	28.7	29.7	30.6	31.6
48	16.5	18.1	19.6	20.9	22.3	23.6	24.8	26.0	27.2	28.2	29.2	30.2	31.2	32.2
50	16.8	18.4	19.9	21.3	22.7	24.0	25.2	26.4	27.6	28.7	29.8	30.8	31.8	32.8
52	17.0	18.7	20.2	21.6	23.1	24.4	25.6	26.8	28.1	29.2	30.3	31.4	32.4	33.4
54	17.3	19.0	20.5	22.0	23.4	24.8	26.1	27.3	28.5	29.7	30.8	31.9	32.9	33.9
56	17.6	19.3	20.9	22.4	23.8	25.2	26.5	27.7	28.9	30.1	31.2	32.4	33.4	34.5
58	17.8	19.5	21.1	22.7	24.2	25.5	26.9	28.2	29.3	30.5	31.7	32.9	33.9	35.0
60	18.1	19.8	21.4	23.0	24.5	25.8	27.3	28.7	29.8	31.0	32.2	33.4	34.5	35.5
62	18.3	20.1	21.7	23.3	24.8	26.2	27.6	29.0	30.2	31.4	32.6	33.8	35.0	36.0
64	18.6	20.3	22.0	23.6	25.2	26.5	27.9	29.3	30.6	31.8	33.1	34.2	35.5	36.5
66	18.8	20.6	22.3	23.9	25.5	26.9	28.3	29.7	31.0	32.2	33.5	34.7	35.9	37.0
68	19.0	20.8	22.5	24.2	25.8	27.3	28.7	30.1	31.4	32.6	33.9	35.1	36.3	37.5
70	19.2	21.	22.8	24.5	26.1	27.6	29.1	30.4	31.8	33.1	34.3	35.6	36.8	37.9

that for large ducts at low velocity the lower surface coefficient of friction for aluminum duct as compared to that for galvanized steel is negligible. However, for small ducts at high velocity the effect can be considerable. With the present trend in air-conditioning systems toward small high velocity ducts, the savings resulting from the use of aluminum ducts may be appreciable.

If rectangular ducts are desired, they can be obtained by using Tables 8-8A, B, C and D listing the circular equivalents of rectangular ducts.

Fittings such as elbows, expansions and the like in a duct system result in dynamic losses (see Figures 8-3, 8-4, and Table 8-9). Since most of the losses due to fittings are caused by turbulence rather than skin friction, the material from which the fittings are fabricated (for conventional duct materials) will have only a small effect on the total loss. Therefore, the charts that have been developed previously for calculating pressure losses are equally applicable to aluminum duct systems.

Some designers may prefer to use Figure 8-5 which permits direct determination of friction losses in 90-degree elbows of round or rectangular cross-section.

The losses due to area changes can be calculated as indicated in the ASHVE Guide. However, in some instances it may be easier to use Figures

TABLE 8-8D: CIRCULAR EQUIVALENTS OF RECTANGULAR DUCTS FOR EQUAL FRICTION AND CAPACITY (Concluded)

DIMENSIONS IN INCHES

SIDE RECTANGULAR DUCT	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	56	60	64	68	72	76	80	84	88	SIDE RECTANGULAR DUCT
20	21.9																										20
22	22.9	24.1																									22
24	23.9	25.1	26.2																								24
26	24.8	26.1	27.2	28.4																							26
28	25.7	27.1	28.2	29.5	30.6																						28
30	26.7	28.0	29.3	30.5	31.6	32.8																					30
32	27.5	28.9	30.1	31.4	32.6	33.8	35.0																				32
34	28.3	29.7	31.0	32.3	33.6	34.8	36.0	37.2																			34
36	29.0	30.5	32.0	33.0	34.6	35.8	37.0	38.2	39.4																		36
38	29.8	31.4	32.8	34.2	35.5	36.7	38.0	39.2	40.4	41.6																	38
40	30.5	32.1	33.6	35.1	36.4	37.6	39.0	40.2	41.4	42.6	43.8																40
42	31.2	32.8	34.4	35.9	37.3	38.6	39.9	41.1	42.4	43.6	44.8	45.9															42
44	31.9	33.5	35.2	36.7	38.1	39.5	40.8	42.0	43.4	44.6	45.8	46.9	48.1														44
46	32.5	34.2	35.9	37.4	38.9	40.3	41.7	43.0	44.3	45.6	46.8	47.9	49.1	50.3													46
48	33.1	34.9	36.6	38.2	39.7	41.2	42.6	43.9	45.2	46.5	47.8	48.9	50.2	51.3	52.6												48
50	33.7	35.5	37.3	38.9	40.4	42.0	43.5	44.8	46.1	47.4	48.8	49.8	51.2	52.3	53.6	54.7											50
52	34.3	36.2	38.0	39.6	41.2	42.8	44.3	45.7	47.1	48.3	49.7	50.8	52.2	53.3	54.6	55.8	56.9										52
54	34.9	36.8	38.7	40.3	42.0	43.6	45.0	46.5	48.0	49.2	50.6	51.8	53.2	54.3	55.6	56.8	57.9										54
56	35.5	37.4	39.3	41.0	42.7	44.3	45.8	47.3	48.8	50.1	51.5	52.7	54.1	55.3	56.5	57.8	58.9	61.3									56
58	36.0	38.0	39.8	41.7	43.4	45.0	46.6	48.1	49.6	51.0	52.4	53.7	55.0	56.2	57.5	58.8	60.0	62.3									58
60	36.5	38.6	40.4	42.3	44.0	45.8	47.3	48.9	50.4	51.8	53.3	54.6	55.9	57.1	58.5	59.8	61.0	63.3	65.7								60
62	37.1	39.2	41.0	42.9	44.7	46.5	48.0	49.7	51.2	52.6	54.2	55.5	56.8	58.0	59.4	60.7	62.0	64.3	66.7								62
64	37.6	39.7	41.6	43.5	45.4	47.2	48.7	50.4	52.0	53.4	55.0	56.4	57.7	59.0	60.3	61.6	62.9	65.3	67.7	70.0							64
66	38.1	40.2	42.2	44.1	46.0	47.8	49.5	51.1	52.8	54.2	55.8	57.2	58.6	59.9	61.2	62.5	63.9	66.3	68.7	71.1							66
68	38.6	40.7	42.8	44.7	46.6	48.4	50.2	51.8	53.5	55.0	56.6	58.0	59.5	60.8	62.1	63.4	64.8	67.3	69.7	72.1	74.4						68
70	39.1	41.3	43.3	45.3	47.2	49.0	50.9	52.5	54.2	55.8	57.3	58.8	60.3	61.7	63.0	64.3	65.7	68.3	70.7	73.1	75.4						70
72	39.6	41.8	43.8	45.9	47.8	49.7	51.5	53.2	54.9	56.5	58.0	59.6	61.1	62.6	63.9	65.2	66.6	69.2	71.7	74.1	76.4	78.8					72
74	40.0	42.3	44.4	46.4	48.4	50.3	52.1	53.9	55.6	57.2	58.8	60.4	61.9	63.3	64.8	66.1	67.5	70.1	72.7	75.1	77.4	79.9					74
76	40.5	42.8	44.9	47.0	49.0	50.8	52.7	54.6	56.3	57.9	59.5	61.2	62.7	64.1	65.6	67.0	68.4	71.0	73.6	76.1	78.4	80.9	83.2				76
78	40.9	43.3	45.5	47.5	49.5	51.5	53.3	55.2	57.0	58.6	60.3	62.0	63.4	64.9	66.4	67.9	69.3	71.8	74.5	77.1	79.4	81.8	84.2				78
80	41.3	43.8	46.0	48.0	50.1	52.0	53.9	55.8	57.6	59.3	61.0	62.7	64.1	65.7	67.2	68.7	70.1	72.7	75.4	78.1	80.4	82.8	85.2	87.5			80
82	41.8	44.2	46.4	48.6	50.6	52.6	54.5	56.4	58.2	60.0	61.7	63.4	64.9	66.5	68.0	69.5	71.0	73.6	76.3	79.0	81.4	83.8	86.2	88.6			82
84	42.2	44.6	46.9	49.2	51.1	53.2	55.1	57.0	58.9	60.7	62.4	64.1	65.7	67.3	68.8	70.3	71.8	74.5	77.2	79.9	82.4	84.8	87.2	89.6	91.9		84
86	42.6	45.0	47.4	49.6	51.6	53.7	55.7	57.6	59.5	61.3	63.0	64.8	66.4	68.0	69.5	71.1	72.6	75.4	78.1	80.8	83.3	85.8	88.2	90.6	92.9		86
88	43.0	45.4	47.9	50.1	52.2	54.3	56.3	58.2	60.1	62.0	63.7	65.4	67.0	68.7	70.3	71.8	73.4	76.3	79.0	81.6	84.2	86 8	89.2	91.6	93.9	96.3	88
90	43.4	45.9	48.3	50.6	52.8	54.8	56.9	58.8	60.7	62.6	64.4	66.0	67.8	69.4	71.1	72.6	74.2	77.1	79.9	82.5	85.1	87.8	90.2	92.6	94.9	97.3	90
92	43.8	46.3	48.7	51.1	53.4	55.4	57.4	59.4	61.3	63.2	65.0	66.8	68.5	70.1	71.8	73.3	74.9	77.9	80.8	83.4	86.0	88.7	91.2	93.6	95.9	98.3	92
94	44.2	46.7	49.1	51.6	53.9	55.9	57.9	60.0	61.9	63.8	65.6	67.5	69.2	70.8	72.5	74.1	75.6	78.7	81.7	84.3	86.9	89.6	92.1	94.6	96.9	99.3	94
96	44.6	47.2	49.5	52.0	54.4	56.3	58.4	60.5	62.4	64.4	66.2	68.2	69.8	71.5	73.2	74.3	76.3	79.4	82.6	85.2	87.8	90.5	93.0	95.6	97.9	100.3	96

8-6, 8-7 and 8-8 which permit direct determination of friction losses.

Heat Losses or Gains: The net heating or cooling effect of a given quantity of air delivered to a room will be greater if the heat losses or gains in the ductwork are minimized. The choice of duct material is important because different metals have different rates of emissivity. Assuming the heat lost from a theoretically perfect black body surface to be 100 percent, the heat loss from an aluminum surface will average only 4-5 percent as compared to 23-28 percent loss for galvanized iron and 80-85 percent loss for black iron. Tests made using 100-foot lengths of 12-inch ducts with same rate of air flow indicate aluminum ducts have greater relative efficiency than bare galvanized iron, galvanized iron covered with asbestos paper, or galvanized iron covered with ¼-inch asbestocel insulation (see Table 8-10).

To determine the actual heat loss through bare aluminum ducts carrying air at a temperature greater than the space ambient temperature, the

following equation can be used

$t_1 \;= K\,(t_2 - t_3) + t_3$

where t_1 = temperature of air at entrance to the duct

t_2 = temperature at end of a 100-foot length of duct

t_3 = ambient temperature of space through which duct runs

K = a coefficient whose value depends on air velocity and on duct diameter (see Figure 8-9).

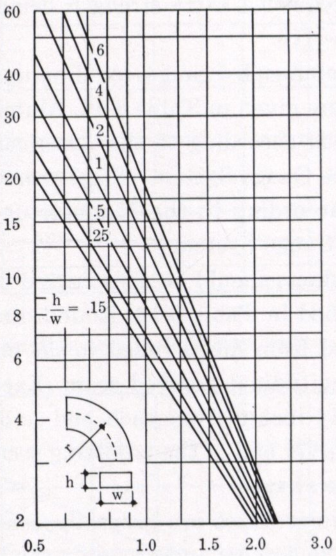


Figure 8-3. Loss in 90-degree elbows of rectangular cross-section expressed in equivalent duct length. (From the "Guide" The American Society of Heating & Ventilating Engineers, 1954.)

For duct lengths other than 100 feet, linear interpolation is not exact but can be used as a means of obtaining an approximate upstream temperature. Where an exact value is required, it can be calculated. See Reynolds, "Aluminum Air Duct Guide."

For bare aluminum ducts carrying air at a temperature less than the space ambient temperature, the following equation can be used

$$t_1 = t_3 - K\,(t_3 - t_2)$$

where all terms are as defined previously.

In the case of insulated air ducts, the heat transfer will depend on the kind and the thickness of the insulation (Figure 8-10), rather than on the material from which the duct is made. Thus the usual methods for calculating heat transfer through insulated aluminum ducts is the same as that used for insulated galvanized iron ducts.

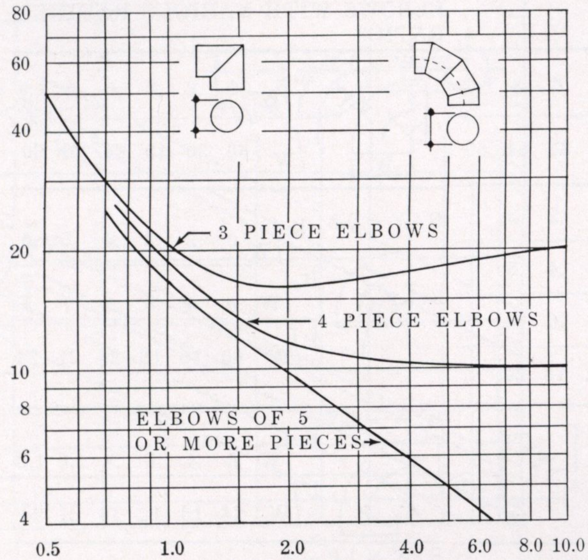


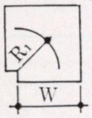
Figure 8-4. Loss in 90-degree elbows of round cross-section expressed in additional equivalent duct length. (From the "Guide" The American Society of Heating & Ventilating Engineers, 1954.)

Duct Design and Construction: The air handling system using aluminum ducts may be designed in accordance with any standard method in common usage today. Whether the design is based upon the "Velocity Reduction Method," "Equal Friction Method," or "Static Regain Method" for duct sizing, the advantages to be obtained by using aluminum ducts are always present. The procedures for using any of the above methods for duct design can be found in Reynolds "Aluminum Air Duct Guide," the "Guide" of the American Society of Heating and Ventilating Engineers, or in any one of several standard textbooks on heating, ventilating and air conditioning. However, in using any of the above methods, the designer should select sizes for aluminum ductwork from charts prepared specifically for aluminum (as presented) in order to obtain the advantage of reduced duct sizes that aluminum affords as compared with galvanized iron (see Figure 8-11).

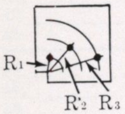
TABLE 8-9: PRESSURE LOSS IN VANED ELBOWS OF SQUARE CROSS-SECTION EXPRESSED IN ADDITIONAL EQUIVALENT DUCT LENGTH

Additional Equivalent Length L = Duct Width W, in Feet, Multiplied by L/W Values Shown

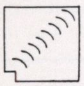
MITER ELBOW



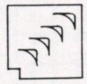
R_1/W	0	.2	.4	.6	.8	1.0
L/W	70	34	28	33	54	60



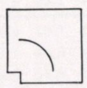
R_1/W	0	.2	.3	.2	.3
R_2/W	0	.4	.5	.4	.5
R_3/W	0	0	0	.6	.7
L/W	70	22	22	18	20

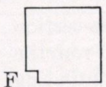

A
L/W = 20


B
14


C
15

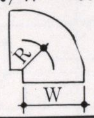

D
L/W = 15


E
28


F
70

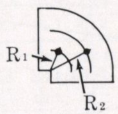
ELBOWS WITH VARIOUS RADIUS RATIOS

R/W = 0.5



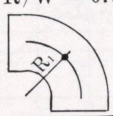
R_1/W	0	.2	.4	.6	.8	1.0
L/W	60	20	19	24	30	60

R/W = 0.5



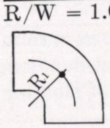
R_1/W	0	.2	.3	.4	.5	.6
R_2/W	0	.4	.5	.6	.7	.8
L/W	60	16	19	20	21	24

R/W = 0.7



R_1/W	0	.4	.6	.8	1.0	1.2
L/W	24	13	12	14	21	24

R/W = 1.0



R_1/W	0	.7	.8	.9	1.0	1.2
L/W	10	8.0	8.0	7.4	7.2	7.4

Vanes: A = a large number of small arc vanes; B = a small number of large arc vanes; C = hollow vanes having different outside and inside curvature; D = four vanes with radius of 0.4 *W*; E = single splitter with radius of 0.5 *W*; F = no vanes or splitters.

TABLE 8-10: RELATIVE EFFICIENCY OF SEVERAL TYPES OF METAL HEATING-DUCTS*

MATERIAL	DIFFERENCE BETWEEN INLET AND OUTLET TEMPERATURES
Bare aluminum	43°F
Bare galvanized iron	52°F
Galvanized iron covered with asbestos paper	61°F
Galvanized iron covered with ¼-in. asbestocel	45°F
Galvanized iron painted with aluminum paint	50°F
Asbestos paper covered galvanized iron wrapped with aluminum foil	38°F

* Comparative Tests of Aluminum and Galvanized Ducts. Sheet Metal Worker, December 1949, page 48.

Aluminum's higher coefficient of thermal expansion must be considered in the design of long ducts and their supports.

Commercially pure aluminum 1100 is suitable for practically all duct work (see Table 8-11). For larger ducts or where additional strength is desired, alloy 3003 may be used. The tempers H18 and H19 have greater strength and hardness but possess less formability; therefore, most fabricators use the H14 and H16 tempers. Probably the most common choice of sheet-metal shops fabricating ductwork would be 1100-H16, with large ducts or ducts requiring extra strength being fabricated from 3003-H16.

The recommended gauges for aluminum rectangular ducts are given in Table 8-12. Aluminum sheets are specified according to the American or Brown and Sharpe Gauge System. (Steel or iron sheets are specified according to the Manufacturer's or U.S. Standard Gauge System.)

Round ducts should be constructed of the thickness specified in Table 8-12. Round ducts are usually formed from sheets rolled to the proper radius with a longitudinal grooved seam. Each section is swaged 1½ inches from each end and assembled with the larger end of the adjoining section butting against the swage.

Rectangular ducts are generally constructed by breaking the corners and grooving the longitudinal seams, or by using a standing seam.

Elbows and transformation sections are generally formed with Pittsburgh corner seams because this seam is easier to lock in place than the double seam. Complicated fittings such as double compounded elbows are usually constructed with double-seam corners. The construction of the various seams and girth connections is shown in Figures 8-12 and 8-13 (see Section 3.5).

The various slips and connections should be as indicated in Table 8-12, and as illustrated in Figures 8-12 and 8-13. The end slip may be used wherever S slips are recommended. Where drive slips are used, the end slip may be applied on the narrow side of the duct and drive slips on only the maximum side.

Aluminum of 16 B & S gauge or heavier can readily be welded by the metallic arc or acetylene process.

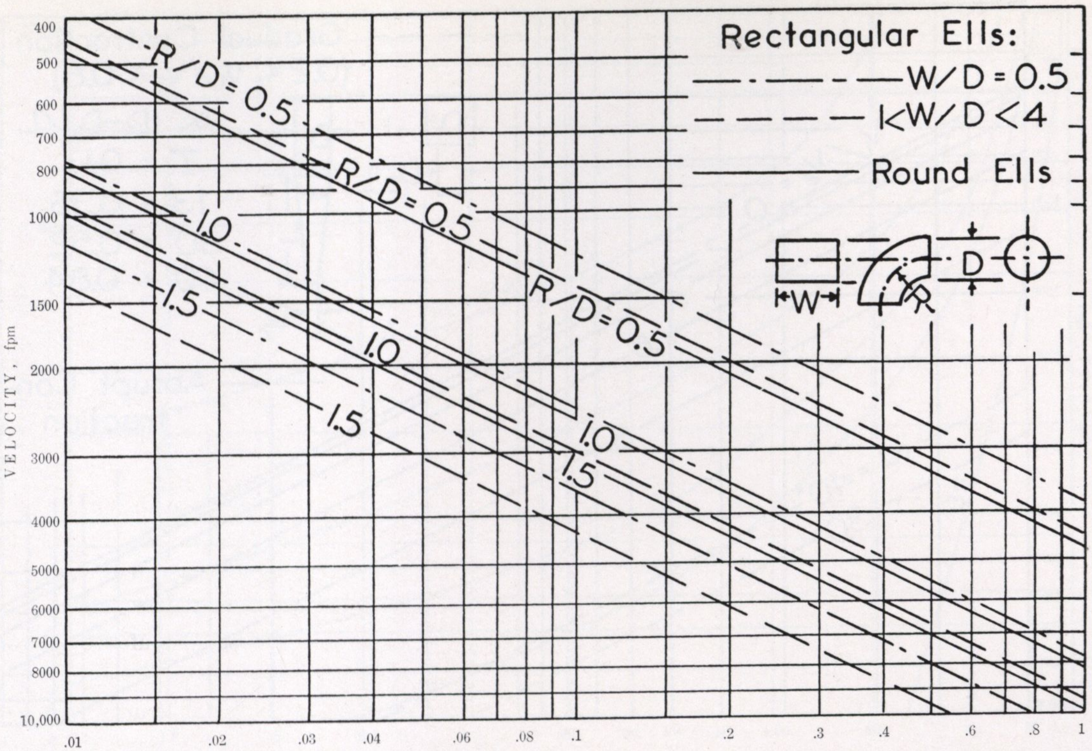


Figure 8-5. Friction loss in inches of water. (From "The Design of Aluminum Duct Systems" by F. W. Hutchinson)

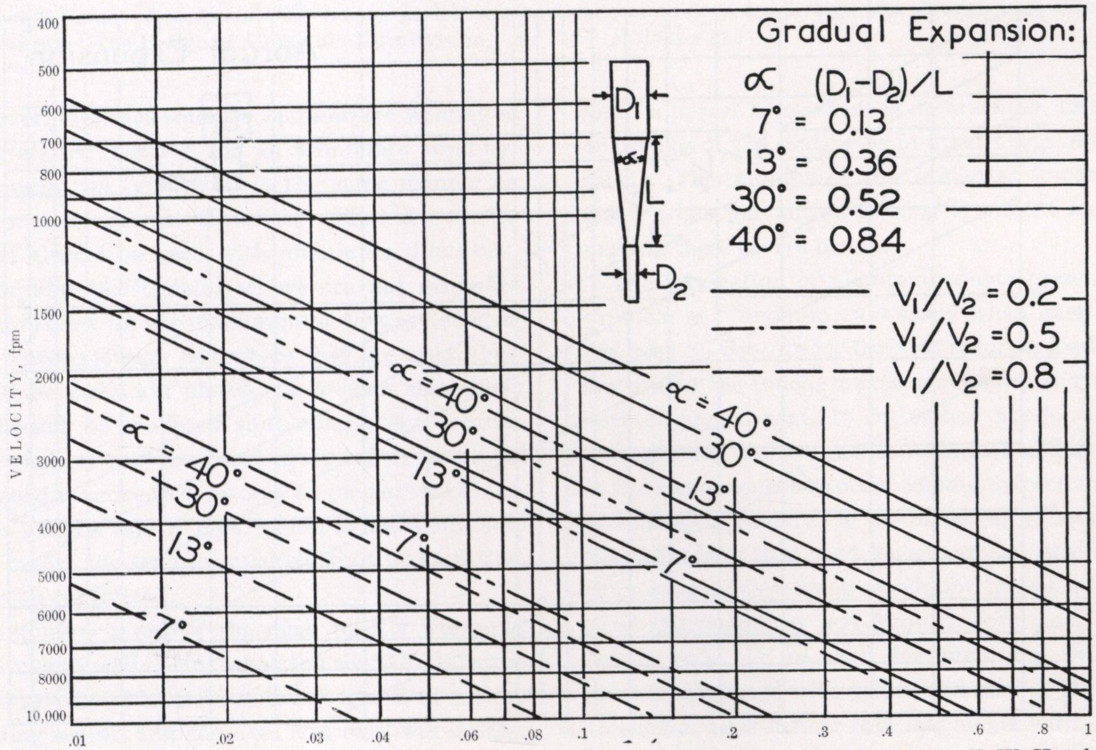


Figure 8-6. Friction loss in inches of water. (From "The Design of Aluminum Duct Systems" by F. W. Hutchinson)

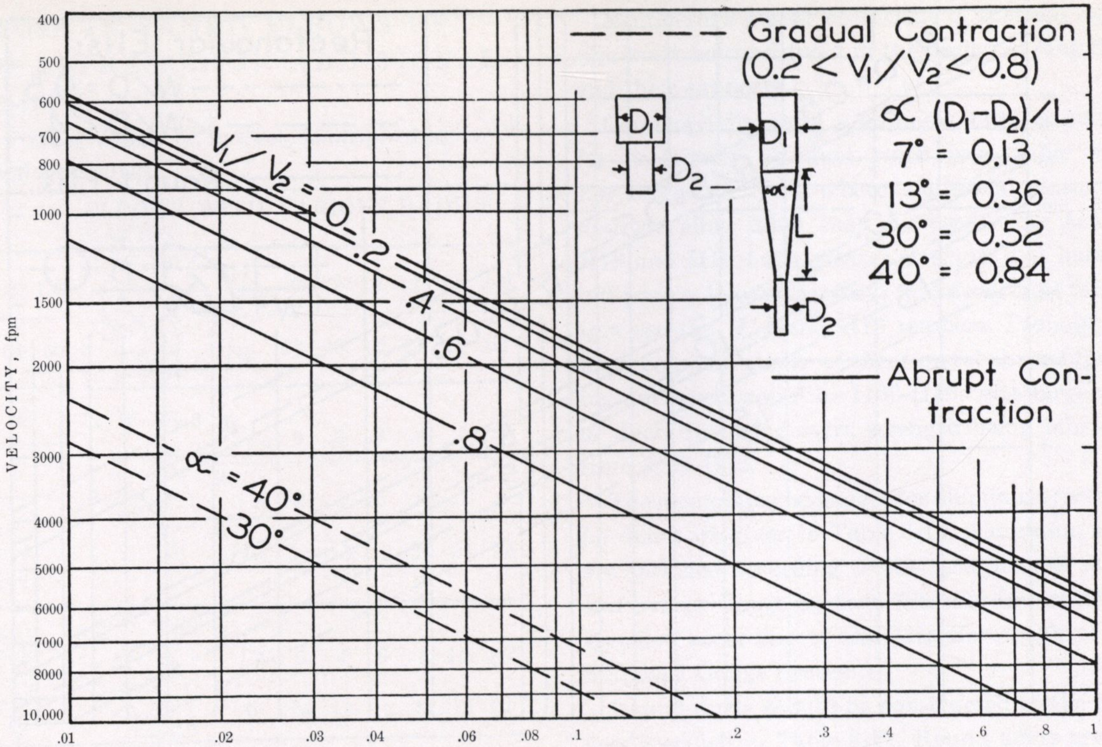


Figure 8-7. Friction loss in inches of water. (From "The Design of Aluminum Duct Systems" by F. W. Hutchinson.)

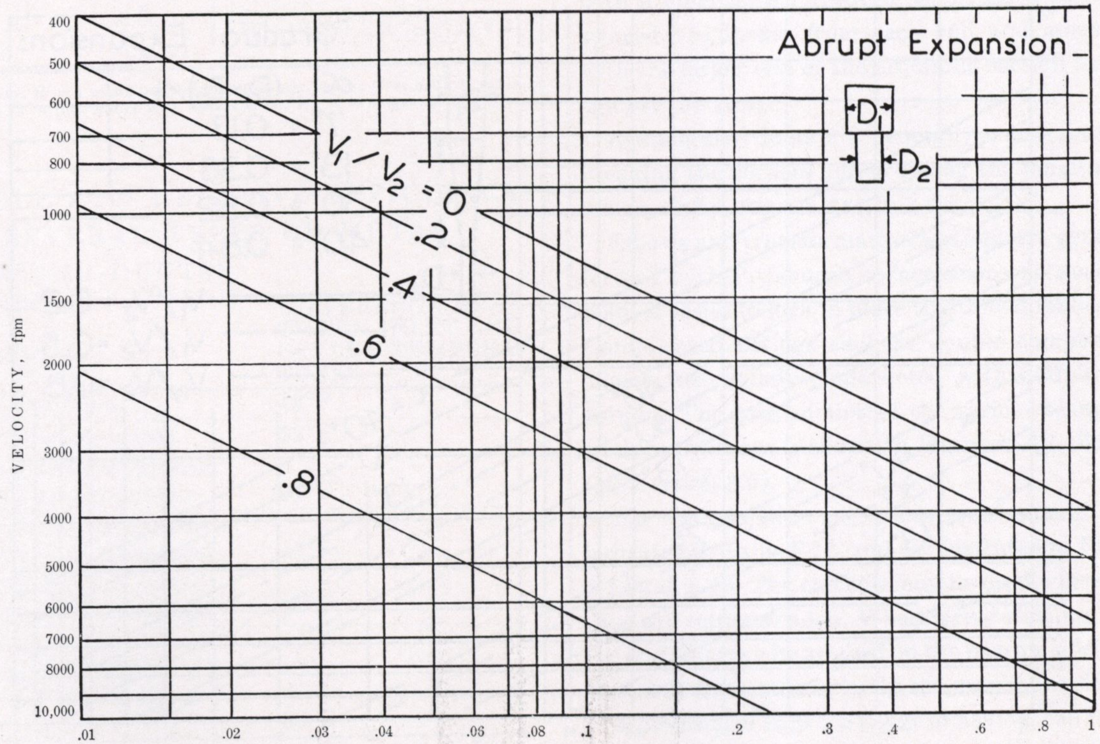


Figure 8-8. Friction loss in inches of water. (From "The Design of Aluminum Duct Systems" by F. W. Hutchinson.)

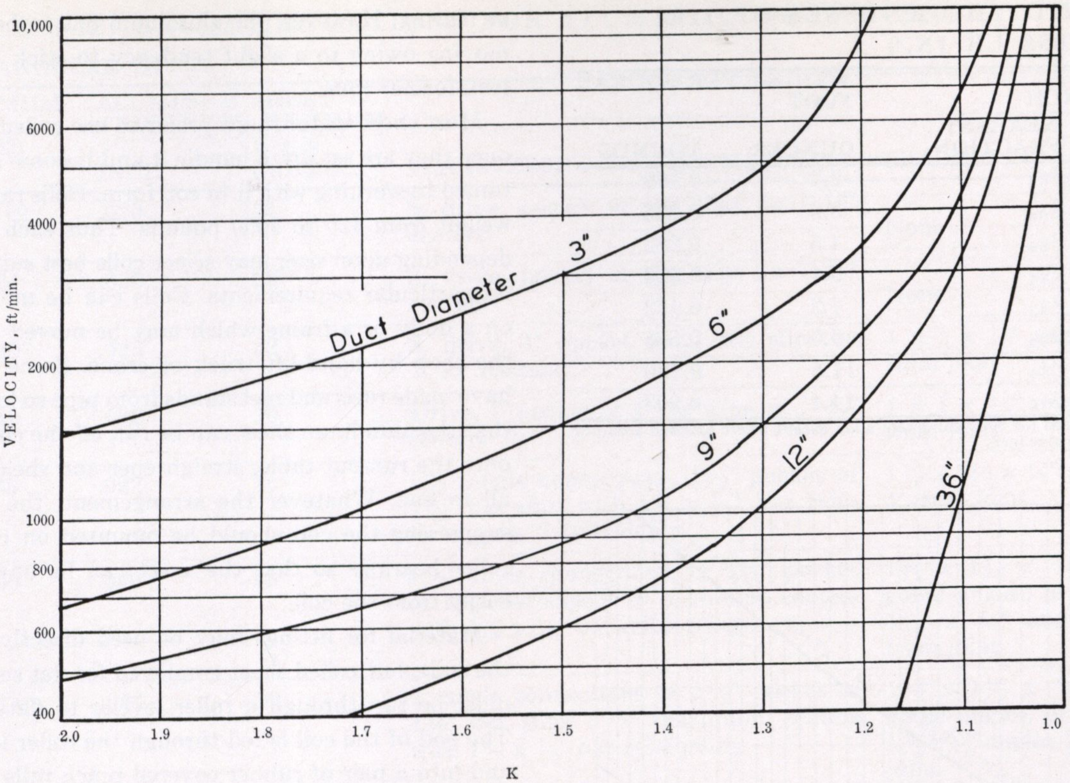


Figure 8-9. Values of coefficient "K" for use in determining temperature drop due to heat loss through bare aluminum ducts. (From "The Design of Aluminum Duct Systems" by F. W. Hutchinson.)

However, inert-gas-shielded metallic-arc welding is the preferred method for all aluminum welding. Aluminum can be riveted in the same manner as iron or steel sheets. However, aluminum rivets should always be used with aluminum ductwork. Self-tapping sheet-metal screws are not generally recommended for use in aluminum duct systems, as they tend to loosen. But where they are used, they should be cadmium plated. Lock-seam assemblies should not be malleted shut completely because some changes may be required during installation. It is good practice to close only an inch or two of the seams at intervals of 8-10 inches in the shop, and then mallet the seam completely shut when fitting has been completed.

Aluminum is one of the most readily workable of all metals and easily takes the sharp 180-degree bends employed in making Pittsburgh lock seams, standing seams, and the like. Not only will it take the severe forming operations, but the completed joint is neater since there is no cracking, breaking or peeling of the coating as in other types of metal sheets. This eliminates the unsightly joints that result when galvanized coating is broken loose in making these severe bends.

The fabrication of aluminum ducts presents no problem as aluminum cuts easily when hand tools are used on cutouts for fittings; it forms readily, is smooth to the touch, makes neat joints and seams with no jagged edges to cut or tear hands.

In general, aluminum may be formed and handled in the same manner as other commonly used metals. No change is required in the blade gap or setting of the shear over that used for galvanized steel of the same gauge. When using aluminum, the shear blades need sharpening at less frequent intervals. Lock-former rolls can be used for aluminum with the same setting used with galvanized steel of the same thickness. Lock-former rolls last longer with aluminum, and little trouble is experienced with wrinkling

TABLE 8-11: WEIGHTS AND THICKNESSES OF 1100 ALUMINUM (DENSITY 0.098 LB/IN.^{3})

B. & S. GAUGE	THICKNESS, INCH		WEIGHT PER SQUARE FOOT	
	DECIMAL	NEAREST FRACTION	OUNCES	POUNDS
28	0.012	1/64	2.7	0.169
26	0.016	1/64	3.6	0.226
24	0.020	1/64	4.5	0.282
22	0.025	1/32	5.4	0.353
20	0.032	1/32	7.2	0.452
18	0.040	3/64	9.0	0.563
16	0.051	3/64	11.5	0.720
14	0.064	1/16	14.4	0.903

Note: Above table for 1100 aluminum can be used for 3003 aluminum alloy except where extreme accuracy is required. Density of 3003 is 0.099 pounds per cubic inch.

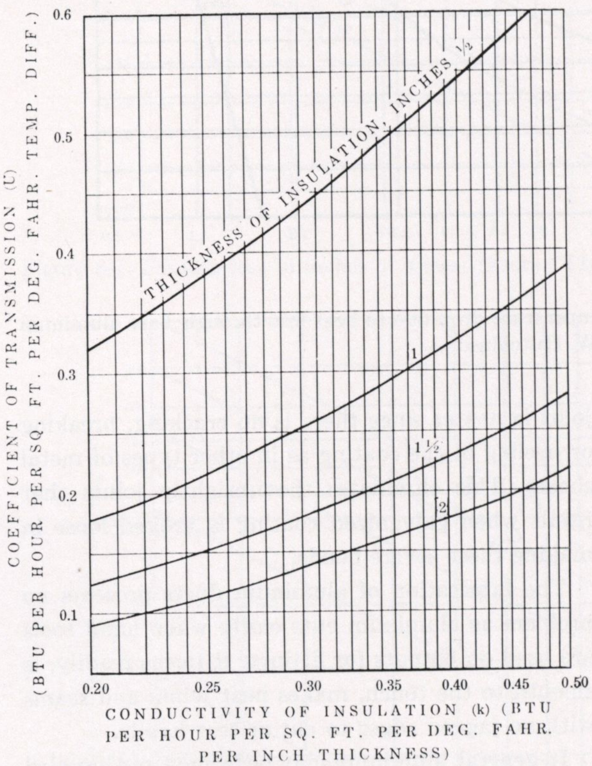


Figure 8-10. Heat loss coefficients for insulated ducts. (From the "Guide" The American Society of Heating & Ventilating Engineers, 1954.)

[a] For round ducts less than 30 in. diameter, increase heat transmission values by the percentages shown below.

THICKNESS OF INSULATION (Inches)	½	1	1½	2
12 to 21 in. Duct Diameter	3%	5%	7%	9%
21 to 30 in. Duct Diameter	1%	2%	3%	4%

or tearing. However, the aluminum has to be kept moving owing to a slight tendency to stick in the lock-former rolls.

Most sheet-metal shops prefer to use coiled sheet once they are set up to handle it and become accustomed to working with it in coil form. Coils range in weight from 420 to 4000 pounds. Thus each shop, depending upon size, may select coils best suited to its particular requirements. Coils can be mounted on a dolly or a frame which may be moved about the shop by hand-lift truck or crane. Some shops have made reels and reel stands from pipe so located that the aluminum sheet can be run off the coil and onto the run-out table, straightener and shear. . . . all in line. Whatever the arrangement, the arbor supporting the coil should be mounted on ball or roller bearings so that the sheet can be unwound easily from the coil.

Material for fittings may be used directly from the coils, but coiled sheet employed for flat sections must be run through a roller leveler to flatten it. The end of the coil is fed through the roller leveler and into a pair of rubber covered pinch rolls fitted with a crank so that they can be turned to pull the sheet through the leveler as it unwinds from the coil. A standard slip roll former can be used for straightening and uncoiling the sheet. From the leveler, the metal goes to the shear and then to the layout table (see Section 3-5).

INSTALLATION: Due to its light weight, aluminum ductwork has a particular advantage over other commonly used metals during erection. Larger sections can be assembled on the ground and raised into position by the workmen. Also, since the weight of aluminum is only one-third that of galvanized steel, an aluminum duct system requires less mechanical support. This results in savings because there are fewer and smaller straps, attachments, inserts and holes to be drilled.

Rolled aluminum angles are recommended for hangers and stiffeners in connection with aluminum ducts. Aluminum supporting members will prevent stains which may occur with steel supports, and will prevent the possibility of electrogalvanic action from contact of dissimilar metals (see Section 2.4).

TABLE 8-12: RECOMMENDATIONS FOR ALUMINUM DUCT CONSTRUCTION

RECTANGULAR DUCTS

MAXIMUM SIDE INCHES	ALUMINUM SHEET THICKNESS, MINIMUM INCH	B & S GAUGE	TRANSVERSE JOINT CONNECTIONS	BRACING
Up to 12	.020	24	S, drive, pocket or bar slips on 7′ 10″ centers	None
13 to 24	.025	22	S, drive, pocket or bar slips on 7′ 10″ centers	None
25 to 30	.025	22	S, drive, 1″ pocket or 1″ bar slips on 7′ 10″ centers	1 x 1 x ⅛″ angles, 4′ from joint
31 to 40	.032	20	Drive, 1″ pocket or 1″ bar slips on 7′ 10″ centers	1 x 1 x ⅛″ angles, 4′ from joint
41 to 60	.032	20	1½″ angle connections, 1½″ pocket or 1½″ bar slips with 1⅜ x ⅛″ bar reinforcing on 7′ 10″ centers	1½ x 1½ x ⅛″ angles, 4′ from joint
61 to 90	.040	18	1½″ angle connections, or 1½″ pocket or 1½″ bar slips 3′ 9″ maximum centers with 1⅜ x ⅛″ bar reinforcing	1½ x 1½ x ⅛″ diagonal angles, or 1½ x 1½ x ⅛″ angles, 2′ from joint
91 and up	.051	16	2″ angle connections or 1½″ pocket or 1½″ bar slips 3′ 9″ maximum centers with 1⅜ x ⅛″ bar reinforcing	1½ x 1½ x ⅛″ diagonal angles, or 1½ x 1½ x ⅛″ angles, 2′ from joint

ROUND DUCTS

DIAMETER, INCHES	ALUMINUM SHEET THICKNESS, MINIMUM INCH	B & S GAUGE
Up to 12	.016	26
12 to 24	.020	24

NOTES:

1. *This table is a modification of one appearing in ASHVE Guide.*
2. *Unless heavy insulation is used, rectangular ducts 18″ and larger should be cross-broken; however, cross-breaking may be omitted if the aluminum sheet thickness is increased by about two gauge numbers for any special reason.*
3. *Bracing angles may be omitted on duct sizes 25″ to 60″ incl. (max. side) if 3′ 9″ section lengths are used.*

Aluminum angles are light to handle, easy to work, readily available and have a good appearance. Typical sizes for air ducts are as follows:

SIZE INCH	THICKNESS INCH	WEIGHT POUNDS PER FOOT
¾ x ¾	3/32	0.16
1 x 1	3/32	0.22
1¼ x 1¼	3/32	0.28
1½ x 1½	3/32	0.34

If aluminum is not used, hangers, braces and fasteners should be hot-dipped galvanized steel. Aluminum rivets should always be used with aluminum ductwork.

Although self-tapping sheet-metal screws are not generally recommended for aluminum ducts, where they are used they should be cadmium plated.

Wherever aluminum ductwork is likely to contact wet or intermittently wet and dry masonry, the masonry or the aluminum should be coated with alkali-resistant paint. Likewise, it is good practice to allow a small clearance around ducts passing through plaster walls in order to reduce the possibility of attack by alkaline elements in the plaster.

8.3 ALUMINUM FOIL AS REFLECTIVE INSULATION AND VAPOR BARRIER

The use of aluminum foil as a building material has

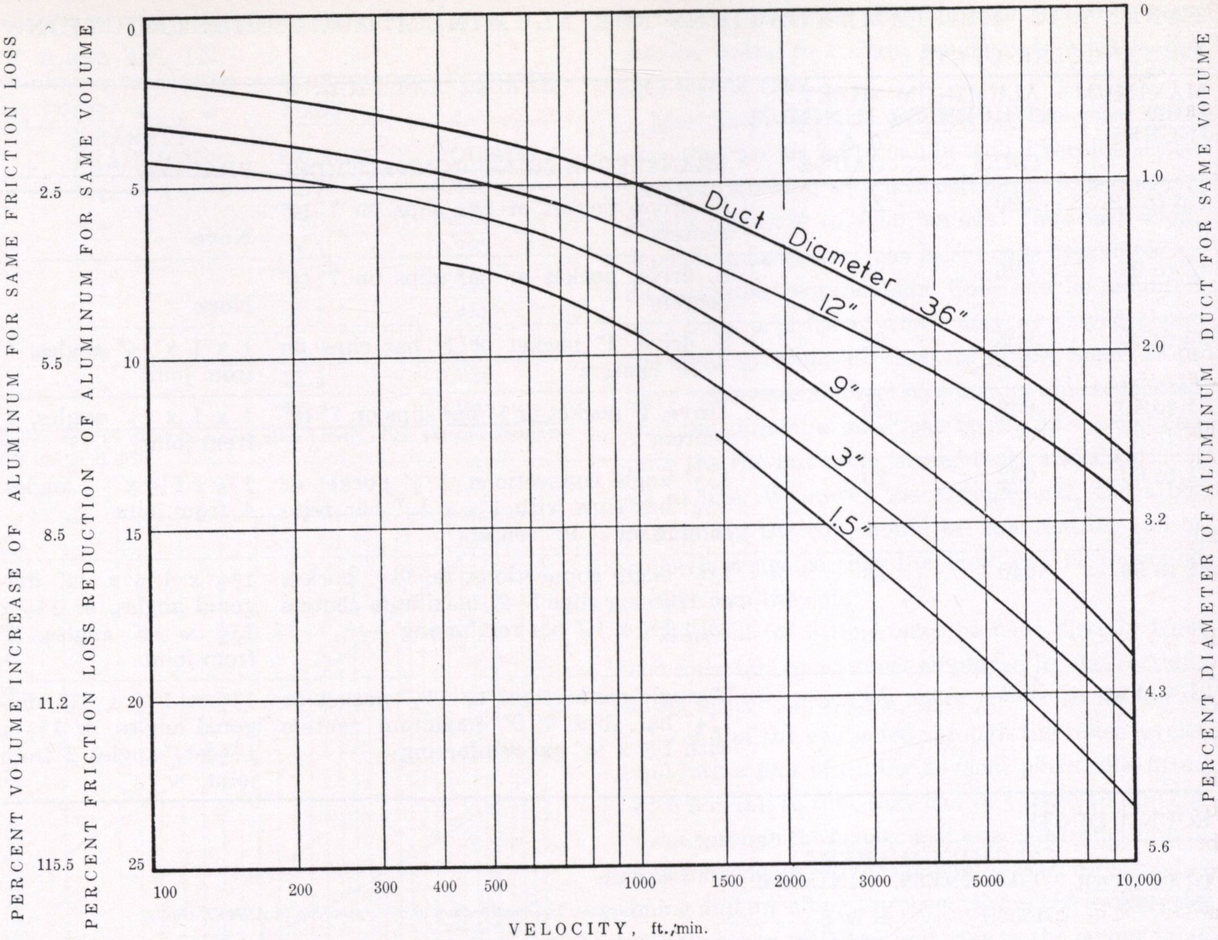


Figure 8-11. Comparison between aluminum vs. galvanized iron ducts. (From "The Design of Aluminum Duct Systems" by F. W. Hutchinson.)

gained wide acceptance because of two essential characteristics:

—It has the highest thermal reflectivity of all suitable and economical materials (95 to 98 percent) and, therefore, can serve as an efficient thermal insulation.

—Aluminum foil, when intact, is vaporproof. It has a very low moisture vapor transmission rating and therefore it makes an effective vapor barrier.

If aluminum foil is properly installed, both of the above characteristics can be utilized simultaneously, as is required in most cases. But even where only one of these properties is of major concern, the other one can still be utilized. While it is possible to install aluminum foil in such fashion that it will serve only one of the two purposes, ordinarily both are utilized.

Due to its non-corrosive characteristics, aluminum retains both its reflectivity and non-permeability indefinitely. Because of this and because of its high efficiency in these two applications, aluminum foil at the present time predominates in these fields. Most common ferrous metals are inferior in reflective power and are also subject to rusting, while protective coatings like lacquers or even oils detract from the reflectivity. Silver, though it has an even higher reflectivity, is uneconomical for ordinary usage in buildings. Bituminous treated papers, even those marketed as vapor barriers, have considerably less resistance to the penetration of water vapor than aluminum foil. Permeability of

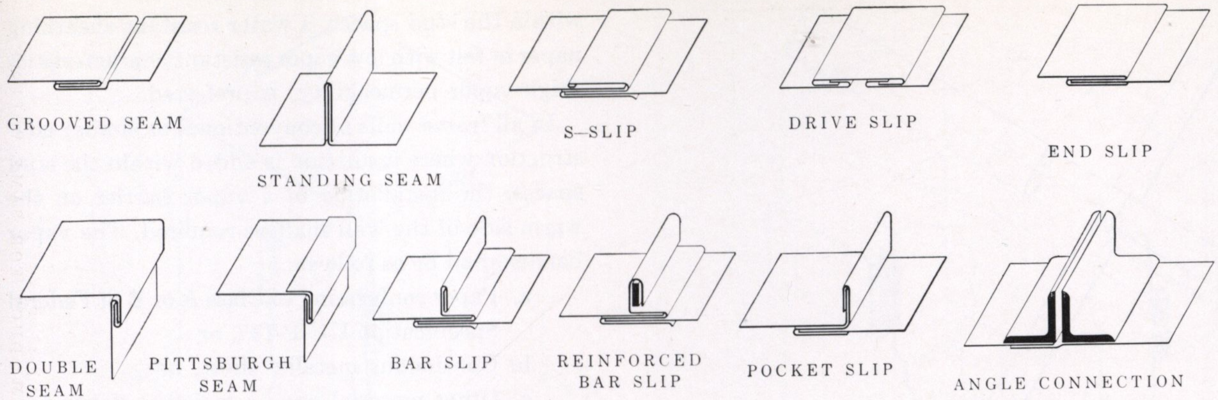


Figure 8-12. Duct seams and connections. (From "Aluminum Sheet Metal Practice in the Building Industry" by Aluminium Company of Canada, Ltd.)

aluminum foil ranges from 0—.129, while treated paper has a permeability of .66—4.07 and higher.

REQUIREMENTS FOR THERMAL INSULATION AND VAPOR BARRIERS:
Criteria for the design of insulation and vapor barriers in buildings are at present based on prevailing practice. Insulation requirements are usually given by specifying the maximum allowable heat loss for both whole units of a building and its components. Vapor barriers are specified by maximum permeability. The current practice for residential construction is represented in the "Minimum Property Requirements" of the Federal Housing Administration, pertinent sections of which follow:

402-A. Insulation

1. The total hourly heat loss of a living unit in Btu shall not exceed 60 times the floor area in square feet. Such floor area shall include closets and interior partitions, but not exterior walls or partitions exposed to unheated spaces.

2. In addition the over-all coefficient of heat transmission in Btu per hour per square foot per degree temperature difference from air inside to air outside or to air in unheated spaces ("U" factor) shall not exceed:

a. 0.15 for a ceiling or portion thereof exposed to an unheated space.

b. The values listed in the following table for exterior walls or partitions exposed to unheated spaces, and for floors over unheated spaces, for the outside design temperature established by the Federal Housing Administration for the locality.

TABLE 8-13

OUTSIDE DESIGN TEMPERATURE °F	WALLS "U" FACTOR	FLOORS "U" FACTOR
−36 and lower	0.15	0.06
−26 to −35 inclusive	.19	.10
−16 to −25 inclusive	.23	.16
−6 to −15 inclusive	.27	.22
−5 to +5 inclusive	.31	.28
+6 to +15 inclusive	.35	.31
+16 to +25 inclusive	.40	.34
+26 to +35 inclusive	.45	.42
+36 and higher	.50	.50

3. The Chief Underwriter may require insulation in excess of 1 and 2 above.

402-B. Vapor Barriers

The vapor resistance of the vapor barrier should be equal to or greater than the total vapor resistance of all materials and construction on the exterior side of the vapor barrier including exterior painting.

In conventional frame walls where sheathing paper is required and where insulation is not added

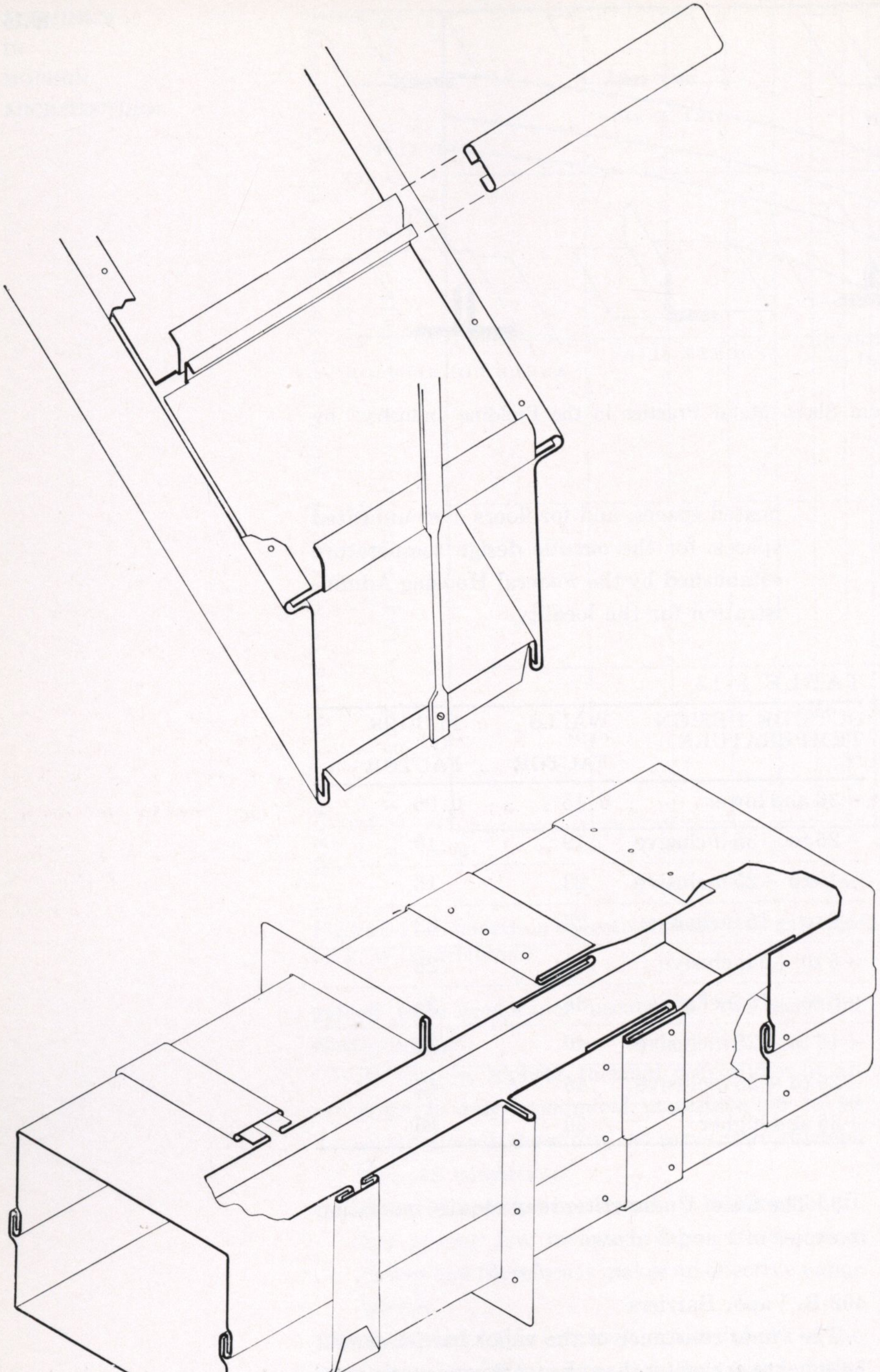


Figure 8-13. Duct constructions details; continued on Page 329. (From "Aluminum Sheet Metal Practice in the Building Industry" by Aluminium Company of Canada, Ltd.)

within the stud spaces, a water resistant sheathing paper or felt with low vapor resistant characteristics (high vapor permeability) is preferred.

In all frame walls of conventional or similar construction where insulation is added within the stud spaces, the installation of a vapor barrier on the warm side of the wall shall be required. The vapor barrier shall be as follows:

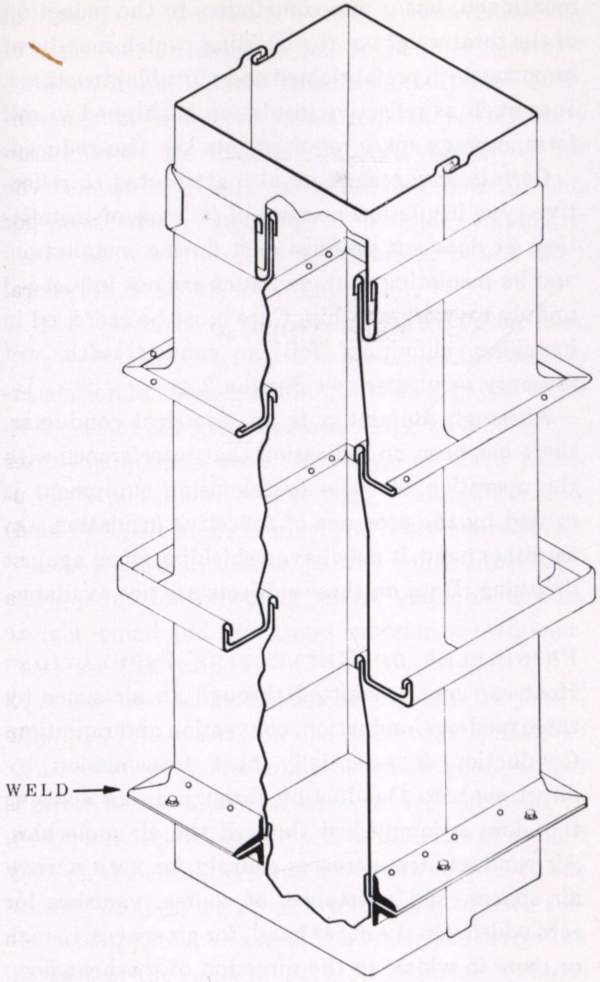
a. Paper conforming to Class A or B of Federal Specification UU-P-147, or
b. Continuous metallic sheet, or
c. Other material having moisture vapor permeability not exceeding:
   (1) 6 grams per 24 hours per square meter at 50 percent vs. 5 percent relative humidity and 73°F. (TAPPI test method) or
   (2) 1 grain per square foot per hour at a vapor pressure difference through the material of 1 inch of mercury or
   (3) 2 grains per square foot per hour at a vapor pressure difference through the material of 1 pound per square inch.

Vapor barriers shall be installed as continuous as practicable and shall be securely fastened at top, sides, bottom and at any intermediate framing. Any perforations of the barrier required for the installation of electric outlet boxes or the like should be made so that there is a minimum of free opening.

These permissible heat loss and U-values are still under discussion, and it is possible that some changes will be made with a view to reducing heat requirements of houses.

In the past, much work has been done to establish insulation requirements based on fuel or cost savings. Uncertainties are inevitable concerning future fuel costs, heating plant efficiency, obsolescence, proper interest on the investment, and the like.

After the permissible heat loss and U-values for the several exposed elements of a house have been established, the insulating material and installation arrangement can usually be selected on the basis of installed cost. Some consideration of durability is in order, but there is no substantial evidence that the materials on the market are not generally satisfactory in this respect, particularly if they are kept dry.



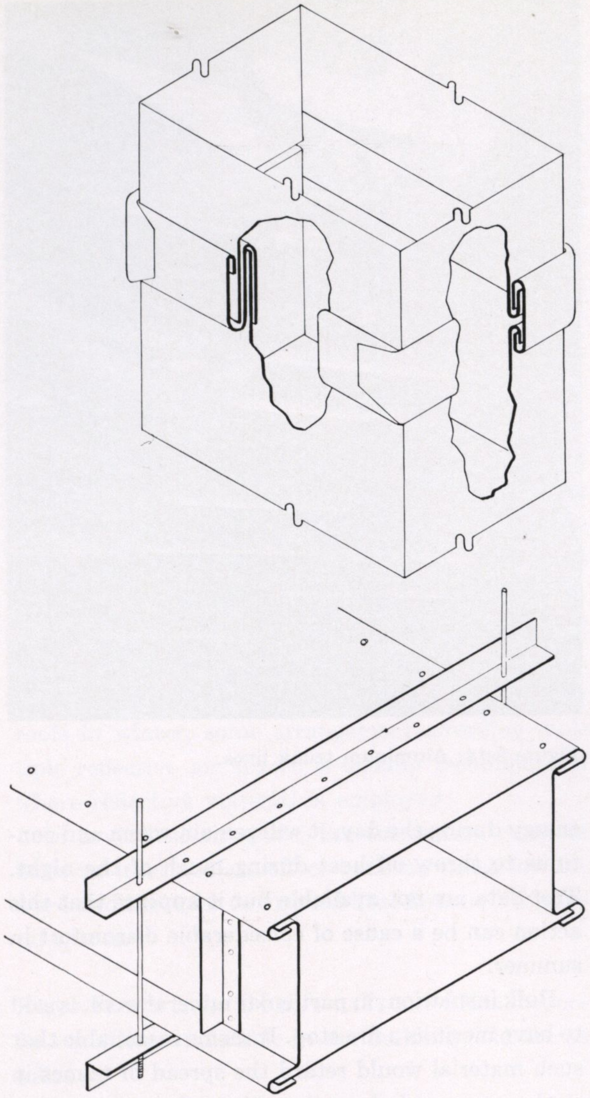


Figure 8-13. Duct constructions Details. (From "Aluminum Sheet Metal Practice in the Building Industry" by Aluminium Company of Canada, Ltd.) (Concluded from Page 328).

ADVANTAGES AND LIMITATIONS OF ALUMINUM INSULATION AND VAPOR BARRIERS: Buildings can be insulated with any of the several forms of reflective insulation or bulk type insulation, or with various combinations of these. Any reasonable U-value can be specified and attained with most any insulation. The installed cost is likely to differ for the same U-value, depending on the cost of labor and material in the various regions. Reflective material is most likely to suffer in such a comparison when a U-value for heat flow upward is specified. This is expected because the convective heat transfer is most active for heat flow upward, as discussed under "Principles of Reflective Insulation" (see below).

It is said for aluminum foil insulation that its low mass and consequent small heat capacity is an advantage in keeping houses cool in summer. The weight of bulk insulation in a house can be considerable, and if the material is heated by solar

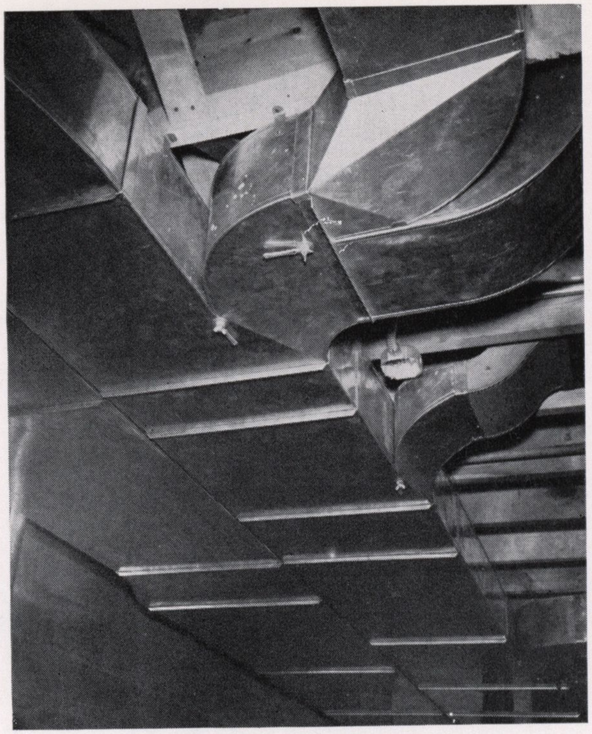


Figure 8-14: Aluminum trunk lines.

energy during the day, it will remain warm and continue to throw off heat during much of the night. Test data are not available but it appears that this action can be a cause of considerable discomfort in summer.

Bulk insulation, in particular mineral wool, is said to have merit as a fire stop. It seems reasonable that such material would retard the spread of flames in stud spaces and through ceilings due to its mass and fire resistance. . . . Noncombustible aluminum foil is preferable to asphaltic paper and other inflammable materials. Because of its low emissivity, aluminum foil is reported to be an effective fire retardant, which is of importance in paper or fiber-backed reflective insulation and in vapor barriers.

The low density of reflective insulation can be appreciated if the weight of the reflective insulation is compared to an equivalent bulk insulating material, such as rock wool for instance. The reflective insulation may weigh as little as 2 to 3 percent of the weight of bulk insulation. This has a bearing not only on heat-storage capacity, as previously mentioned, but it also contributes to the reduction of the total weight of the building, which may be of importance in prefabricated and portable structures. Inasmuch as reflective insulation is shipped in roll form, storage space requirements are also reduced.

Certain advantages are also attributed to reflective type insulation because of its ease of installation. It does not produce dust during installation, and its insulating characteristics are not influenced unduly by workmanship. Care must be exercised in installing aluminum foil in contact with wet masonry or plaster (see Section 2-4).

Although aluminum is an electrical conductor, there has been no indication that interference with the operation of radio or television equipment is caused by the presence of reflective insulation. On the other hand, it may have a shielding effect against lightning. Data on these subjects are not available.

Principles of Reflective Insulation: Heat can be transmitted through an air space by three modes: Conduction, convection and radiation. Conduction is essentially heat transmission by direct contact. Conduction through an air space is therefore accomplished through the air molecules. Air conductance increases sharply for very narrow air spaces, and resistance, of course, vanishes for zero width. On the other hand, for air spaces ¾-inch or more in width, in the direction of the heat flow, conduction through air plays an insignificant part in heat transfer and can be ignored for most practical purposes. This fact is an important factor in the insulation of buildings, since the distance between exterior and interior surfaces of walls and floors is usually considerably greater than ¾-inch.

Heat transfer by convection occurs through the movement of air and, in ordinary types of construction, accounts for 15-50 percent of the total heat transmission. Convection is influenced by the orientation of the air space and the direction of the flow.

Radiation is the transmission of energy through space. As can be seen from the previous data, this type of transfer accounts for a substantial percentage of the heat flow in all practical instances under consideration. Since radiant heat transmission is reduced by the use of reflective insulation, the ap-

plication of aluminum foil of 95 percent reflectivity will prevent at least one half of the total heat flow through the air space. This accounts for the effectiveness of reflective insulation. It is obviously desirable to use materials of high reflectivity (or low emissivity), such as aluminum foil, for this purpose. When designing a building employing reflective insulation, the following facts and their implications should be considered:

The reflectance of surfaces is affected by the wave length of the incident light or radiant heat. As reflective insulation in a house wall, for instance, glossy white paint is not effective. For heat (long wave lengths), white paint acts about the same as black paint, while a metal surface like that of aluminum may reflect 95 percent or more of the radiation received. On the other hand, white paint is much superior to dark paint for reflecting direct sunlight and is, in fact, equal and sometimes superior to metal surfaces for this purpose.

It does not matter whether the reflective surface is applied to the warmer or the cooler side of the stud space so far as the radiant heat is concerned. A poor emitter is also a poor absorber of radiant heat. In effect, a reflective surface acts as a barrier to radiant heat regardless of the direction of flow. However, the futility of applying reflective material to both surfaces is apparent because, if one surface arrests 95 percent of the radiation, the other surface can operate only upon the remaining five percent. If, however, a sheet of material with both sides reflective is installed in the middle of the stud space, forming two air spaces each with a reflective surface, the insulating effect will be approximately doubled. Multiple air spaces are resistant to heat flow approximately in proportion to their number.

Aluminum foil should not be placed in contact with sheathing. In that position the foil will be cold in winter and water vapor, migrating through the wall, may condense on the foil. Such foil can be placed advantageously on or near the back of wallboard or plaster. In that position the foil retards the emission of heat across the stud space. Being an excellent vapor barrier, the foil also protects the wall structure from condensation of water vapor originating in the house. Furthermore, due to contact or proximity to the wall or plasterboard, the foil will usually be sufficiently warm to preclude condensation on its own surface.

The radiant heat transfer across an air space is not affected by orientation, that is, the radiant transfer is the same horizontally across a vertical air space, upward through a horizontal air space, or downward through a horizontal air space. This, however, is not true of convection. In a horizontal air space with heat flow downward, the air stratifies and convection almost ceases. Thus an air space with a single reflective surface is, comparatively, an excellent insulator against heat flow downward.

This fact favors reflective materials for insulating floors over cold spaces in winter and for insulating ceilings or attics to exclude heat in summer. On the other hand, the convection currents are vigorous in a horizontal air space with heat flow upward. A reflective sheet, therefore, affects a smaller part of the heat transfer. Consequently, for reducing upward heat flow, such as that through ceilings or roofs in winter, some arrangement affording multiple reflective air spaces is usually recommended where reflective material is employed.

In a vertical air space, the convection currents have an intermediate effect between those for upward and those for downward heat flows in horizontal spaces.

EQUATIONS AND COMPUTATIONS: Heat transfer equations applicable in the building field are as follows:

TRANSMITTANCE: Heat transfer through an outside wall, roof, exposed floor or ceiling is the special conductance

$$Q = U\,(t_i - t_o) \qquad (1)$$

where

Q = heat flow, Btu per hour per square foot

U = transmittance factor, Btu per hour for one square foot and for a temperature difference of 1°F between the air inside and that outside the building

t_i = temperature, inside, °F

t_o = temperature, outside, °F

CONDUCTANCE: Heat flow through a wall or other heat barrier from a surface to another surface parallel to the first is

$$Q = C\ (t_1 - t_2) \tag{2}$$

where

Q = heat flow, Btu per hour per square foot

C = conductance factor, Btu per hour for one square foot and for a temperature difference of 1°F between the two surfaces

t_1 = temperature, warmer surface, °F

t_2 = temperature, cooler surface, °F

Also, the conductance factor is equal to the inverse of the total thermal resistance of the heat barrier between the two surfaces considered; thus

$$C = \frac{1}{r_1 + r_2 + \ldots + r_n} = \frac{1}{R} \tag{3}$$

where

$r_1 + r_2 + \ldots + r_n$ = the individual resistance of the components of the heat barrier.

R = total resistance of the heat barrier

Also, the transmittance factor is equal to the inverse of the total resistance of the wall, floor, roof or ceiling including the film resistance on the two sides; thus

$$U = \frac{1}{r_i + r_o + r_1 + r_2 + \ldots + r_n} = \frac{1}{R} \tag{4}$$

where

r_i = inside air film resistance to heat flow from air to surface of wall, ceiling, roof or floor

r_o = outside air film resistance to heat flow from surface to air

The thermal resistance of a homogeneous* material is its thickness divided by its conductivity; so

$$r = \frac{L}{k} \tag{5}$$

where

L = length of heat path = thickness of material, inches

k = conductivity, Btu per hour, for 1 square foot for a temperature difference of 1°F through a thickness of 1 inch

* Homogeneous in the heat transfer sense; a mass of fibers is not strictly homogeneous since it contains both fibers and air spaces, but it is being treated as such for present purposes.

Values of conductivity, k, for various materials are determined by laboratory tests and are published in various references.

RADIANT HEAT TRANSFER ACROSS AN AIR SPACE:

$$q_r = 0.172 \left[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4 \right] E \tag{6}$$

where

q_r = heat flow by radiation across an air space, Btu per hour for 1 square foot

T_1 = surface temperature, warm side, °F absolute

T_2 = surface temperatures, cool side, °F absolute

E = emissivity factor; depends on nature of surfaces of space

EMISSIVITY FACTOR FOR AN AIR SPACE:

$$E = \frac{1}{\frac{1}{P_1} + \frac{1}{P_2} - 1} \tag{7}$$

where

P_1 = emissivity, warm side

P_2 = emissivity, cool side

COMBINED RADIATION AND CONVECTION ACROSS AIR SPACES:

$$q_{rc} = C_{rc}\ (T_1 - T_2) \tag{8}$$

where

q_{rc} = heat flow across an air space due to combined effects of radiation and convection, Btu per hour per square foot

C_{rc} = coefficient of heat transfer by radiation and convection; Btu per hour per square foot per degree F temperature difference between the warm and the cool sides. Some values of this factor can be computed from the data in Table 8-14

CONVECTION HEAT TRANSFER: No equation for the transfer of heat across an air space by convection has been generally accepted. Therefore, to

determine the convection transfer, when it is required, total conductance is determined by laboratory test and the radiant transfer, computed by Equation 6, is deducted.

Some selected materials of interest in the building field are given in Table 8-14.

The effective emissivity E of an air space can be computed by means of Equation 7 and the data in Table 8-14 as follows:

Example A: Assume the stud space in a house wall to be bounded on one side by paper-backed wallboard and on the other side by wood sheathing:

From Table 8-14, $P_1 = 0.92$; $P_2 = 0.90$;

$$\text{then } E = \frac{1}{\frac{1}{0.92} + \frac{1}{0.90} - 1} = \frac{1}{1.20} = 0.83$$

Example B: Consider the same air space as in Example A, except the wall board is backed with aluminum foil which faces the air space.

From Table 8-14, $P_1 = 0.04$; $P_2 = 0.9$

$$E = \frac{1}{\frac{1}{0.04} + \frac{1}{0.90} - 1} = \frac{1}{25.1} = 0.04$$

The radiant heat transfer across an air space can be computed by means of Equation 6, and the results of Equation 7 as shown in Examples A and B, as follows:

Example C: Assume in an air space

Warm surface temperature, 60°F, = 460 + 60 = 520°F

Cool surface temperature, 30°F, = 460 + 30 = 490°F

The radiant heat flow for "black body" condition is given by that portion of Equation 6 exclusive of the Emissivity Factor, E.

Therefore

$$q_r = 0.172\left[\left(\frac{520}{100}\right)^4 - \left(\frac{490}{100}\right)^4\right] = 0.172\,[(5.2)^4 - (4.9)^4]$$

$$= 26.3 \text{ Btu per hour per square foot.}$$

If the air space has no reflective surfaces, as in Example A, the heat transfer by radiation becomes

Example D: 0.83 x 26.3 = 21.8 Btu per hour per square foot.

If the air space has one reflective side, as in example B, the heat transfer by radiation becomes

TABLE 8-14: SURFACE EMISSIVITIES

SURFACE	TEMPERATURE °F	EMISSIVITY p
Aluminum, Polished	73	0.04
Al. Powder on Paper	—	0.15 to 0.35
Wrought Iron, Polished	100-480	.28
Galvanized Iron, Bright	82	.23
Brick, Red, Rough	70	.93
Porcelain	72	.92
Marble, Polished	72	.92
Wood (Oak, Planed)	70	.90
Paper	66	.92
Roofing Paper	69	.91
Plaster	50-190	.91

TABLE 8-15: THERMAL RESISTANCES* (R_{rc}) OF 1½-INCH AIR SPACES

TEMP. DIFF. = 20°F MEAN TEMP. = 50°F

ORIENTATION OF SPACE	DIRECTION OF HEAT FLOW	EFFECTIVE EMISSIVITY (E) OF SPACE			
		0.05	0.20	0.50	0.82
Horizontal	Down	5.7	3.2	1.7	1.1
45° angle	Down	3.9	3.6	1.5	1.0
Vertical	Horizontal	2.8	2.0	1.3	0.9
Horizontal	Up	2.0	1.6	1.1	.8
45° angle	Up	2.3	1.8	1.2	.9

* Degrees F per Btu per hour per square foot. $1/R_{rc} = C_r$ in Equation 8.

Example E—0.04 x 26.3 = 1.05 Btu per hour per square foot.

The equations discussed are fundamental to heat flow computations. Data based on direct experiment are given in Table 8-15.*

The data in Table 8-15 apply to the total heat flow due to both radiation and convection across an air space. The data can be applied to spaces wider than 1½ inches for estimating purposes.

EFFECTIVENESS: The effects of reflective insulation applied to some typical structural elements are shown in Tables 8-16, 8-17 and 8-18. The data quoted here for convenience were taken from "The

* These data were extracted from "The Thermal Insulating Value of Air Spaces" HHFA Bulletin 32 issued by the Housing and Home Finance Agency, Washington 25, D. C. available from Superintendent of Documents, Government Printing Office, Washington 25, D. C.

TABLE 8-16: U-VALUES FOR WALLS—EFFECT OF INSULATION IN STUD OR FURRING SPACE

INSULATION IN SPACE	EMISSIVITY OF SPACE	WALL U-VALUE
3-inch Wall of Brick and Cinder Block with Furring Strips and Plasterboard		
None	0.82	0.25
Reflective Paper on Plasterboard	.20	.20
Aluminum Foil on Plasterboard	.05	.18
Fibrous Insulation	—	.17
Timer Wall of Lap Siding, Sheathing, with Plaster on Plasterboard		
None	0.82	0.24
Aluminum Foil on Plasterboard	.05	.18
Aluminum Sheet, middle of Stud Space (forming two reflective air spaces)	.05	.12
Reflective Paper, Dbl. Faced, Middle of Space	.20	.14
2-Inch Fibrous Insulation, No Reflective Surface	.82	.085
Three Reflective Spaces Formed by Two Sheets of Aluminum Foil	.04	.077

TABLE 8-17: U-VALUES FOR CEILINGS—EFFECT OF INSULATION BETWEEN JOISTS*

INSULATION IN JOIST SPACE	EMISSIVITY OF SPACE	U-VALUES HEAT FLOW UP	DOWN
None	0.82	0.30	0.25
Aluminum Foil on Plasterboard	.05	.22	.088
Reflective Paper on Plasterboard	.20	.24	.156
Aluminum Sheet, Middle of Space (forming two reflective spaces)	.05	.146	.052
Reflective Paper, Middle of Space	.20	.17	.105
4-Inch Fibrous Insulation, No Foil	.82	.055	.053

* Plaster on plasterboard supported by 2 x 8 joists with single-thickness pine floor above.

TABLE 8-18: U-VALUES FOR FLOORS—EFFECT OF INSULATION BETWEEN JOISTS*

INSULATION IN JOIST SPACE	EMISSIVITY OF SPACE	U-VALUES HEAT FLOW DOWN
None	—	0,28
Aluminum Foil on Bottom of Joists	0.05	.07
Reflective Paper, Bottom of Joists	.20	.12
½-Inch Insulating Board—Bottom of Joists	.82	.16
2-Inch Fibrous Blanket, Air Space Above	—	.08

* Double floor, paper between, on 2 x 10 joists, no ceiling below.

Thermal Insulating Value of Air Spaces" and are based on work done at the National Bureau of Standards.

It is, of course, possible to compute heat transfer coefficients by means of the theory and data given under Equations and Computations above but it is simpler and usually safer to extract them from tables based on direct experiment when available.

TYPES OF REFLECTIVE INSULATION: Flat aluminum foil purchased in rolls for insulating purposes is likely to be .0003 to .0015-inch in thickness and is available in various widths up to at least 36 inches. It is also available in accordion folded strips with flanges for easy stapling, for up to 24-inch centers in .0015-inch thickness. Such material can be conveniently attached to timber by means of stapling tools. Cardboard "battens" are sometimes used to permit better sealing between foil and timber when the flanges are not an integral part of the foil. This sealing at joints is important to prevent convection around the edges. The thinner foils are fragile and must be carefully handled to avoid tearing. Thicker foils are relatively tough; foil .0015 inch thick is said to have a tearing strength of 64 grams.

Paper-backed aluminum foil has some advantages in strength and workability compared to thin foil. Both single-faced and double-faced paper-backed foils are available. The material is installed and fastened substantially like plain foil and the same insulating effects are expected of it.

Reflective paper is prepared by the application of aluminum powder or flake material to the surface of paper sheet. The emissivity of this material is usually higher than that of foil, in the range of .15-.35 instead of .04, expected of foil. Reflective papers are to some degree permeable to water vapor which is advantageous when it is desirable to place a reflective surface on or near the cold side of a wall, floor or other exposed structural element.

Combinations of bulk and reflective insulation offer important advantages. Those with an aluminum foil outer surface (facing to outside of building) will reflect up to 95 percent of the radiant heat energy striking them. This high reflectivity is important in reducing the heat stored in the bulk insulation. The outer foil surface has small holes punched in it at regular intervals to permit moisture from the bulk insulation to escape outward. Those combinations of bulk and reflective insulation that employ reflective paper as the outer surface will reflect approximately 80 percent of the radiant heat energy striking them.

Combinations of bulk and reflective insulation can be classified into three groups: Type A employs aluminum foil to completely encase the batt of bulk insulation on all four sides. Type B uses foil only on the inner surface (facing inside of building); the outer being kraft paper coated with polished aluminum pigment. Type C has a layer of foil on the inner side of the batt only; the outer side being uncovered.

All these various combinations of bulk and reflective insulation employ aluminum foil on the side toward the interior of the building. When intact and installed with proper joints, this foil is almost a perfect vapor barrier, effectively preventing ingress of water vapor from the house into the bulk insulation. When installing any of these insulations, it thus is very important to be sure that the solid foil surface faces the interior of the house.

Plasterboard or wallboard is available with a reflective surface of aluminum foil on one side. Wallboard or plasterboard alone is not usually considered insulating material, but if it is installed with such a reflective surface facing an air space, such as that between the furring strips on a masonry wall, a considerable insulating effect results.

A well-known insulation designed for conserving heat in winter and for excluding solar heat in summer is termed "accordion pleated aluminum foil insulation". This is composed of two or more sheets of aluminum foil or of foil and paper, and it is furnished folded or rolled so that material for a large area can be shipped in a relatively small package. This insulation may be applied to walls, roofs or ceilings or to floors over exposed spaces to reduce heating requirements of buildings in winter or air-conditioning loads in summer. The object of the design is to obtain the effect of multiple reflective air spaces in a self-sufficient material that is

applied like a single sheet of material.

CONDENSATION IN BUILDINGS: Water vapor in dwellings comes from perspiration and exhalation of the occupants as well as from cooking, washing, potted plants, unvented devices burning fuel containing hydrogen, and the like. Due to these factors the absolute humidity is usually higher inside an occupied house than outdoors, particularly in winter when the house is kept closed for warmth. Humidity in houses is reduced by infiltration or ventilation, condensation on windows and migration of water vapor through walls, ceilings and floors.

If water vapor is allowed to migrate excessively through walls or other exposed building elements, condensation may occur within the structure with resultant wetting and damage to insulation or other building parts. For this reason vapor barriers are a usual component of insulated walls, and materials consisting of paper treated with bituminous substances are available for this purpose. Aluminum foil is practically vaporproof, and this attribute can be utilized when the foil is employed for heat insulation. The vapor barrier, be it either aluminum foil or some other material, must be placed in a warmer region of a wall to avoid condensation on the barrier itself and to retard the migration of water vapor toward the colder parts of the wall.

Window condensation is often an indicator of excessive humidity. Houses and buildings should be so constructed that condensation occurs on windows before it does on walls or other parts. Data on humidities for incipient window condensation are given in Table 8-19.

A theory* on condensation has been developed, based on an assumed proportionality of vapor pressure to vapor transfer by diffusion. This theory, however, is not much used for three reasons: The assumed proportionality is not generally accepted, the permeability of materials is uncertain, and the probability of improper installation makes a very high factor of safety essential in selecting vapor barriers. Present practice indicates the following procedures for dwelling houses:

—Install no insulation in contact with roof boards or roof decks on the underside.

—Provide an air space between insulation and roof boards or deck above. If fibrous insulation is used, the air space should be ventilated with outdoor air by louvers or other means.

* Moisture Condensation in Building Walls by H. W. Worley. NBS BMS Report 65.

TABLE 8-19: COMPUTED RELATIVE HUMIDITIES IN BUILDINGS FOR INCIPIENT WINDOW CONDENSATION

OUTSIDE TEMP. °F	COMPUTED INSIDE RELATIVE HUMIDITY (%) FOR WINDOW CONDENSATION			MEAN OF OBSERVED INSIDE RELATIVE HUMIDITY (%) FROM BMS 56	
				HUMIDIFIER	
	SINGLE GLAZED NO WIND	SINGLE GLAZED WIND 15 MPH	DOUBLE GLAZED WIND 15 MPH	YES	NO
40	59	44	73	45	31
30	49	32	66	30	27
20	40	24	59	25	22
10	33	18	51	21*	18*
0	27	13	46		
−10	21	10	40		
−20	19	6	36		

* Extrapolated.

Inside temperature assumed: 70°F. Also, mean of inside relative humidities observed during survey of residence, reported in NBS BMS Report No. 56.

—Provide a vapor barrier at or near the interior surface of insulated walls. Aluminum foil on the back of gypsum lath is a practically perfect vapor barrier. Good commercial vapor barrier material will serve.

—Allow no high resistance to vapor migration outside of the insulation. Pervious paper only should be used on sheathing.

These precautions result in walls, roofs and ceilings that are less subject to condensation than windows under all ordinary conditions.

Ventilation is the usual means for preventing excessive humidity in dwellings in winter. The real purpose of vapor barriers is to prevent condensation in damageable parts like walls, roofs and ceilings before it appears on windows where, in small quantity, the resulting water is harmless. Infiltration, which is natural or accidental ventilation due to leaks in the structure, is sufficient to prevent condensation in many houses, particularly those built some time ago.

A new modern house, weatherstripped or fitted with storm windows and insulated with aluminum foil, is likely to be nearly airtight. This is good from the standpoint of fuel conservation, but deliberate ventilation may be necessary to prevent excessive humidity in the house as well as to expel odors and keep the air fresh. Partial opening of windows may be sufficient but exhaust fans for occasional use are desirable in kitchens, baths and laundry rooms.

In summer, a house is likely to be either air conditioned or copiously ventilated by open windows and doors. In either case the humidity maintained is not directly involved with the insulation. Summer condensation usually results from heat lag due to mass, as in the case of a concrete floor or masonry wall. When such a mass, cooled by a period of cool weather, is exposed to warm, humid air due to a change in weather, condensation may occur.

Since humidity control is part of any air conditioning system, condensation is not expected in an air-conditioned house.

Aluminum Foil as a Vapor Barrier: Aluminum sheet, if intact, is vaporproof. In a house or building, therefore, the material can be a perfect vapor barrier if the joints between sheets are tight.

For this reason it is usual for insulation, either consisting of such foil or having it as a component, to form its own vapor barrier. If the foil is used in conjunction with bulk insulation, economy dictates that both the vapor-resisting property and the insulating property of the foil should be utilized. To accomplish this, (1) the reflective surface of the foil must face an air space and (2) the foil should be on the warm side of the bulk insulation. Thus, in a frame wall, for instance, a blanket of bulk insulation with aluminum foil on one side must be installed with the foil toward the plaster and with an air space, preferably an inch or more in width, between the foil and the plaster. Infiltration of air through the clapboards and sheathing will ordinarily be sufficient to carry away water vapor migrating through leaks in the joints if aluminum foil is installed with reasonable care.

Bituminous-treated papers, even those marketed as vapor barriers, have much less resistance to water vapor than aluminum foil. It is therefore impractical to protect a blanket of mass insulation with a sheet of ordinary vapor barrier material on the warm side when it has a sheet of aluminum foil on the cold side.

BIBLIOGRAPHY

ALUMINUM AIR DUCT GUIDE by Reynolds Metals Company.

ALUMINUM SHEET-METAL PRACTICE IN THE BUILDING INDUSTRY by Aluminium Company of Canada, Ltd.

ALUMINUM IN HEATING, VENTILATING, AIR CONDITIONING by Reynolds Metals Company.

THE DESIGN OF ALUMINUM DUCT SYSTEMS by F. W. Hutchinson, Kaiser Aluminum & Chemical Sales, Inc.—1954

HEAT TRANSMISSION by McAdams—McGraw-Hill.

HEAT INSULATION by G. B. Wilkes—John Wiley & Sons.

HEATING, VENTILATING, AIR CONDITIONING GUIDE by the American Society of Heating and Air Conditioning Engineers.

THE THERMAL INSULATING VALUE OF AIR SPACES, HHFA Bulletin 32 issued by the Housing and Home Finance Agency, Washington 25, D. C.

CONDENSATION IN BUILDINGS by R. S. Dill—Letter Circular 863, National Bureau of Standards, Washington 25, D. C.

MOISTURE CONDENSATION IN BUILDING WALLS by H. W. Woolley, National Bureau of Standards, Washington 25, D. C.

BUILDING INSULATION by P. D. Close, American Technical Society, Chicago, Illinois.

MINIMUM PROPERTY REQUIREMENTS by Federal Housing Administration, Washington 25, D. C.

INDEX TO THE APPENDIX

TABLE A2-1: CONVERSIONS FROM COMMERCIAL DESIGNATIONS TO AA NUMBERS

OLD DESIGNATION	AA NUMBER	OLD DESIGNATION	AA NUMBER	OLD DESIGNATION	AA NUMBER
99.3[1]	1230	XC16S	X2316	Alclad 61S	Alclad 6061
99.35, R995	1235	17S	2017	62S	6062
99.6, CD1S	1160	A17S	2117	63S	6063
99.75[2]	1175	18S	2018	B64S	6264
99.8, CC1S	1180	B18S	2218	X64S	X6064
99.85, DB1S	1285	F18S, RR58	2618	XA64S	X6164
99.87, EB1S	1187	XA19S	X2119	66S	6066
EC[3]	EC	24S	2024	70S	7070
AA1S	1095	Alclad 24S	Alclad 2024	XC70S	X7370
AB1S	1085	25S	2025	72S	7072
AC1S	1070	B25S	2225	XB72S	X7272
AD1S	1050	32S	4032	X73S	X7073
AE1S	1030	43S, K145	4043	75S	7075
BA1S	1099	C43S, 44S, K143	4343	Alclad 75S	Alclad 7075
BB1S	1188	XE43S	X4543	XC75S	X7375
BC1S, R998	1080	44S, C43S, K143	4343	76S	7076
BD1S	1060	45S	4045	B77S	7277
BE1S	1145	X47S	X4047	XA78S	X7178
CA1S	1197	50S	5050	X79S	X7079
CB1S	1185	Alclad 50S	Alclad 5050	XB80S	X8280
CC1S, 99.8	1180	A50S, R305, K155	5005	XC80S	X8380
CD1S, 99.6	1160	XD50S	X5405	XD80S	X8480
DB1S, 99.85	1285	A51S	6151	HZM100	7001
DD1S	1260	XB51S	X6251	K112	8112
DE1S	1330	J51S, K160	6951	K143, C43S, 44S	4343
EB1S, 99.87	1187	52S	5052	K145, 43S	4043
FB1S	1090	F52S	5652	K155, A50S, R305	5005
FC1S	1170	XE52S	X5006	K157, C57S	5357
HC1S	1270	53S	6053	K160, J51S	6951
JC1S	1075	B53S	6253	K162, R306[4]	6003
2S	1100	C53S	6353	LK183	5083
A2S	1200	XD53S	X6453	K186	5086
3S	3003	E53S	6553	R301 Core, 14S	2014
Alclad 3S	Alclad 3003	A54S	5154	R301, Alclad 14S	Alclad 2014
4S	3004	B54S	5254	R305, K155, A50S	5005
Alclad 4S	Alclad 3004	X55S	X5055	R306, K162[4]	6003
XA5S	X3005	AlcladX55S	Alclad X5055	R308[5]	1130
11S	2011	56S	5056	R399	8099
14S, R301 Core	2014	Alclad 56S	Alclad 5056	R995, 99.35	1235
Alclad 14S, R301	Alclad 2014	XC56S	X5356	R998, BC1S	1080
XB14S	X2214	C57S, K157	5357	RR58, F18S	2618
XB16S	X2216	61S	6061		

[1] Cladding on Alclad 24S (Alclad 2024).
[2] Cladding on No. 2 Reflector Sheet.
[3] EC—The designation for electrical conductor metal is not being changed since it is so firmly established in the electrical industry.
[4] Cladding on R301 and Alclad 14S (Alclad 2014).
[5] No. 1 Reflector Sheet.

TABLE A2-2: CONVERSIONS FROM AA NUMBERS TO COMMERCIAL DESIGNATIONS

AA NUMBER	OLD DESIGNATION	AA NUMBER	OLD DESIGNATION	AA NUMBER	OLD DESIGNATION
EC[1]	EC	2117	A17S	5652	F52S
1030	AE1S	X2119	XA19S	6003[5]	R306, K162
1050	AD1S	X2214	XB14S	6053	53S
1060	BD1S	X2216	XB16S	6061	61S
1070	AC1S	2218	B18S	Alclad 6061	Alclad 61S
1075	JC1S	X2219	. . .	6062	62S
1080	BC1S, R998	2225	B25S	6063	63S
1085	AB1S	X2316	XC16S	X6064	X64S
1090	FB1S	2618	F18S, RR58	6066	66S
1095	AA1S	3003	3S	6151	A51S
1099	BA1S	Alclad 3003	Alclad 3S	X6163	. . .
1100	2S	3004	4S	X6164	XA64S
1130[2]	R308	Alclad 3004	Alclad 4S	X6251	XB51S
1145	BE1S	X3005	XA5S	6253	B53S
1160	CD1S, 99.6	4032	32S	6264	B64S
1170	FC1S	4043	43S, K145	6353	C53S
1175[3]	99.75	4045	45S	X6453	XD53S
1180	CC1S, 99.8	X4047	X47S	6553	E53S
1185	CB1S	4343	C43S, 44S, K143	6951	J51S, K160
1187	EB1S, 99.87	X4543	XE43S	7001	HZM100
1188	BB1S	5005	A50S, R305, K155	7070	70S
1197	CA1S	X5006	XE52S	7072	72S
1200	A2S	5050	50S	X7073	X73S
1230[4]	99.3	Alclad 5050	Alclad 50S	7075	75S
1235	R995, 99.35	5052	52S	Alclad 7075	Alclad 75S
1260	DD1S	X5055	X55S	7076	76S
1270	HC1S	Alclad X5055	AlcladX55S	X7079	X79S
1285	DB1S, 99.85	5056	56S	X7178	XA78S
1330	DE1S	Alclad 5056	Alclad 56S	X7272	XB72S
2011	11S	5083	LK183	7277	B77S
2014	14S, R301 Core	5086	K186	X7370	XC70S
Alclad 2014	R301, Alclad 14S	5152	. . .	X7375	XC75S
2017	17S	5154	A54S	8099	R399
2018	18S	5254	B54S	8112	K112
2024	24S	X5356	XC56S	X8280	XB80S
Alclad 2024	Alclad 24S	5357	C57S, K157	X8380	XC80S
2025	25S	X5405	XD50S	X8480	XD80S

[1] EC—The designation for electrical conductor metal is not being changed since it is so firmly established in the electrical industry.
[2] No. 1 Reflector Sheet.
[3] Cladding on No. 2 Reflector Sheet.
[4] Cladding on Alclad 2024 (Alclad 24S).
[5] Cladding on Alclad 2014 (R301 and Alclad 14S).

Notes to Tables A2-1 and A2-2:
The old commercial designations consisted essentially of a numeral and the letter S, e.g., 17S. Modifications of the original alloy were denoted by a preceding letter, used consecutively in alphabetical order, e.g., A17S. Certain other letters preceding the numeral were sometimes used to indicate the producer of the alloy; the letter X denoted an alloy in the experimental stage.

The numeral identified the major alloying element; a range of numerals was assigned to each major element. Numerals within this range were used for different alloy compositions with the same major alloying element, according to the following table:

NUMERICAL RANGE	MAJOR ALLOYING ELEMENT
2 S	Commercially pure aluminum
3 S to 9 S	Manganese
10 S to 29 S	Copper
30 S to 49 S	Silicon
50 S to 69 S	Magnesium
70 S to 79 S	Zinc

TABLE A2-3: TEMPER CONVERSION TABLE FOR NON-HEAT-TREATABLE WROUGHT ALUMINUM PRODUCTS*

TEMPER DESIGNATIONS PRIOR TO DEC. 31, 1947	TEMPER DESIGNATION EFFECTIVE SINCE DEC. 31, 1947		
	If strain hardened only	If strain hardened and then partially annealed	If strain hardened and then stabilized
-¼ H	-H 12	-H 22	-H 32
-½ H	-H 14	-H 24	-H 34
-¾ H	-H 16	-H 26	-H 36
-H	-H 18	-H 28	-H 38
Extra-Hard	-H 19	. . .	-H 39

* Also available in -O and -F tempers.

Notes to Table A2-3:
The main difference between old and present temper designations for non-heat-treatable alloys consists in that the old designation merely indicated the temper condition, such as ¼ hard (¼H), ½ hard, etc., while the present designation specifies the type of hardening treatment as well. (See also Table 2-2).

Notes to Tables A2-5 (Aluminum Mill Product Specifications), and Table A2-6 (Aluminum Ingot and Casting Specifications):

Alloy Numbers (Table A2-5, Columns 1-3 and Table A2-6, Columns 1-3). Alloy numbers identify the alloys on the basis of their chemical compositions.

Products (Column 4, Table A2-5). This column lists mill products of the respective alloys for which specifications have been issued.

Alloy Specifications (Table A2-5, Columns 5-8 and Table A2-6, Columns 4-7). Alloy specifications establish the requirements which a certain mill product of a particular alloy composition has to meet for the purchasing needs of a government agency or a certain industry.

In addition to the specifications listed there are Army, Air Force, Navy, and Air Force—Navy Aeronautical specifications. However, these specifications are to be replaced by the Federal and Military Specifications and are, therefore, not included here.

Federal Specifications (Table A2-5, Column 5 and Table A2-6, Column 4). Federal specifications are issued under the direction of the Administrator of General Services for procurement use by the Government Agencies and Departments. Departmental or other specifications may be used only if no suitable Federal Specification is available or if the applicable Federal Specification does not cover the grade of material required.

These specifications establish values for minimum ultimate and yield tensile strength and elongation, in addition to specifying many other requirements, such as chemical composition, tolerances, markings for identification, workmanship, etc.

Tolerances on all aluminum wrought products covered by Federal specifications are in accordance with the latest issue of QQ-A-245.

Copies of Federal specifications can be purchased from the General Services Administration, Washington 25, D.C. Single copies may be obtained free of charge from the nearest Regional Office of General Services Administration.

Military Specifications (Table A2-5, Column 6 and Table A2-6, Column 5). Military specifications are issued by the Office of Standards, Defense Supply Management Agencies for use by the Armed Forces for the procurement of such products or the control of such processes which are peculiar to them and not covered adequately by Federal Specifications. Originally this series was the Joint Army-Navy series of specifications so that some specifications in the series are still identified by the old "JAN" symbol. These will be changed to "MIL" as they are revised. In the majority of cases the remaining portion of the designation will remain the same. Copies of these specifications can be obtained from the cognizant bureau or department or any Government Agency using the specification.

AMS Specifications (Table A2-5, Column 7 and Table A2-6, Column 6). The Aeronautical Material Specifications Division of the Society of Automotive Engineers, which is composed of representatives from the manufacturers and suppliers of the aircraft industry, issues this series of specifications. Copies can be purchased from the Society of Automotive Engineers, 29 West 39th Street, New York, N. Y. Successive revisions of a specification are indicated by a capital letter (A, B, C, etc.) following the number.

ASTM Specifications (Table A2-5, Column 8 and Table A2-6, Column 7). The ASTM specifications constitute a widely recognized set of commercial standards. The specification number (called ASTM Designation) is in two parts; that to the left of the dash indicating the material, product or process defined, and that to the right showing the year in which the specification last was revised. Designations beginning with B cover light metals and alloys including aluminum and aluminum alloys. Those beginning with D cover miscellaneous materials such as paint, wood, oil and the like, including aluminum pigments. All designations beginning with E cover various methods of testing or analysis.

Copies of ASTM specifications may be purchased individually from the Society's Office at 1916 Race Street, Philadelphia 3, Pennsylvania.

TABLE A2-4: TEMPER CONVERSION TABLE FOR HEAT-TREATABLE WROUGHT ALUMINUM PRODUCTS

ALLOY DESIGNATION	OLD TEMPER DESIGNATION PRIOR TO DEC. 31, 1947	NEW TEMPER DESIGNATION SINCE DECEMBER 31, 1947													
		SHEET AND PLATE[1]					WIRE, ROD AND BAR[1]—ROLLED OR COLD-FINISHED	ROLLED STRUCTURAL SHAPES[1]	EXTRUDED ROD, BAR, SHAPES, TUBING AND PIPE[1]		DRAWN TUBING AND PIPE[1]		FORGINGS[2]	RIVETS	
		FLAT SHEET		COILED SHEET	PLATE										
		Heat-Treated by Producer	Heat-Treated by Customer	Heat-Treated by Producer or Customer	Heat-Treated by Producer	Heat-Treated by Customer	Heat-Treated by Producer	Heat-Treated by Producer or Customer	Heat-Treated by Producer	Heat-Treated by Customer	Heat-Treated by Producer	Heat-Treated by Customer	Heat-Treated by Producer or Customer	Heat-Treated by Producer or Customer	Driven Rivets
	–W	...	...	...	...	...	–T4	...	...	...	...	...	...	...	...
2011	–T3	...	...	...	...	...	–T3	...	...	...	...	...	...	...	...
	–T8	...	...	...	...	...	–T8	...	...	...	...	...	...	...	...
	–W	...	...	...	...	...	...	–T4	–T4	–T42	...	...	–T4	...	...
2014	–T	...	...	...	...	...	...	–T6	–T6	–T62	...	...	–T6	...	...
	–T	...	...	...	...	...	...	...	...	...	...	...	–T61[3]	...	...
	–T	...	...	...	...	...	–T4	–T4	...	...	...	...	...	–T4	–T3[4]
2017	–T	...	...	...	...	...	...	...	...	...	...	...	...	...	–T31[5]
	–T	...	...	...	...	...	...	...	...	...	...	...	...	...	–T41[6]
	–T	–T3	–T4	–T4	–T4	–T42	–T4	...	–T4	–T42	–T3	–T4	...	–T4	–T31[5]
	–RT	–T36	...	...	–T36	...	–T36	...	...	...	...	...	...	...	...
2024 and Alclad 2024[7]	–T80	...	...	–T6	...	...	...	...	...	...	...	...	...	...	...
	–T81	–T81	...	...	...	...	...	...	...	...	...	...	...	...	...
	–T86	–T86	...	...	–T86	...	...	...	...	...	...	...	...	...	...
	–W	...	...	...	...	...	...	...	...	...	...	...	–T4	–T4	–T4
6053	–W	...	...	...	...	...	...	...	...	...	...	...	...	...	–T41[6]
	–T	...	...	...	...	...	...	...	...	...	...	...	–T6	–T6	–T6
	–T61	...	...	...	...	...	...	...	...	...	...	...	...	–T61	–T61
	–W	–T4	–T4	–T4	–T4	–T4	–T4	–T4	–T4	–T4	–T4	–T4	...	...	...
	–T	–T6	–T6	–T6	–T6	–T6	–T6	–T6	–T6	–T6	–T6	–T6	...	–T6	–T6
6061	–T5	...	...	...	...	...	...	...	–T5	...	...	...	...	...	...
	–T62	...	...	...	...	...	...	–T62	–T62	–T62	...	...	...	...	...
	–T81	...	...	...	...	...	–T81	...	...	...	...	...	...	...	...
	–T7	...	...	...	...	...	–T91	...	...	...	...	...	...	...	...
	–F	...	...	...	...	...	...	...	–T42	...	...	...	...	...	...
6063	–T	...	...	...	...	...	...	...	–T6	–T6	...	...	...	...	...
	–T5	...	...	...	...	...	...	...	–T5	–T5	...	...	...	...	...
7075 and Alclad 7075[7]	–W	–W[8]	–W[8]	–W[8]	–W[8]	–W[8]	–W[8]	...	–W[8]	–W[8]	...	...	...	...	...
	–T	–T6	–T6	–T6	–T6	–T6	–T6	...	–T6	–T6	...	...	...	...	...

[1] Products listed are also available in –O and –F tempers.
[2] Forgings are also available in –F temper.
[3] Boiling water quench.
[4] Driven cold after full natural aging.
[5] Driven cold immediately after solution heat treatment, or when refrigerated to defer natural aging.
[6] Driven hot, at the solution heat-treating temperature.
[7] Available only in the form of sheet and plate.
[8] To be specific, the time of natural aging must be stated, for example, 7075-W (2 hours) 7075-W (2 months).

TABLE A2-5: ALUMINUM MILL PRODUCT SPECIFICATIONS

ALLOY NUMBER			PRODUCT	ALLOY SPECIFICATIONS			
AA 1	ASTM 2	SAE 3	4	FEDERAL 5	MILITARY 6	AMS 7	ASTM 8
1100	990A	25	Plate & Sheet	QQ-A-561b	...	4001B 4003B	B209-54T
			Plate & Sheet for Pressure Vessels	...	...	...	B178-53T
			Bar, Rod, Wire & Shapes; Rolled or Drawn	QQ-A-411C	...	4102A	B211-53T
			Bar, Rod & Shapes; Extruded	...	...	...	B221-53T
			Bar, Rod & Shapes for Pressure Vessels	...	...	...	B273-53T
			Tubes, Drawn	WW-T-783b	...	4062B	...
			Wave Guide Tubes	...	MIL-T-85B-1	...	...
			Foil	...	MIL-A-1486B	...	...
			Rivet Wire	...	MIL-W-7986	...	...
			Rivets	...	MIL-R-5674A-1	7220B	...
			Spray Gun Wire	...	MIL-W-6712	4180A	...
			Welding Rod	QQ-R-566	MIL-E-16053C	...	B184-43T
3003	M1A	29	Plate & Sheet	QQ-A-359c	...	4008B	B209-54T
			Plate & Sheet for Pressure Vessels	...	...	...	B178-53T
			Bar, Rod & Shapes; Rolled or Drawn	QQ-A-356c	...	...	...
			Bar, Rod & Shapes; Extruded	QQ-A-357	...	...	B221-53T
			Bar, Rod, & Shapes for Pressure Vessels	...	...	...	B273-53T
			Tubes; Drawn	WW-T-788b	...	4065B 4067B	B210-54T
			Tubes; Extruded	...	...	...	B235-53T
			Pipe & Tubes for Pressure Vessels	...	...	...	B274-53T
			Condenser Tubes	...	...	...	B234-53T
			Pipe	...	...	...	B241-53T
			Foil	...	...	4010	...
			Rivet Wire	...	MIL-R-1150A-1	...	...
			Rivets	...	MIL-R-1150A-1	...	...

TABLE A2-5: ALUMINUM MILL PRODUCT SPECIFICATIONS (Continued)

ALLOY NUMBER			PRODUCT	ALLOY SPECIFICATIONS			
AA 1	ASTM 2	SAE 3	4	FEDERAL 5	MILITARY 6	AMS 7	ASTM 8
Alclad 3003	Clad M1A	...	Plate & Sheet for Pressure Vessels	...	...	...	B178-53T
			Condenser Tubes	...	...	...	B234-53T
3004	MG11A	20	Plate & Sheet	...	...	...	B209-54T
			Plate & Sheet for Pressure Vessels	...	...	...	B178-53T
			Tubes; Drawn	...	...	...	B210-54T
			Pipe & Tube for Pressure Vessels	...	...	...	B274-53T
Alclad 3004	Clad MG11A	...	Plate & Sheet for Pressure Vessels	...	...	...	B178-53T
4043	...	...	Welding Rod	QQ-R-566	MIL-E-16053	4190A	B184-43T
5050	G1A	...	Plate & Sheet	...	...	...	B209-54T
			Plate & Sheet for Pressure Vessels	...	...	...	B178-53T
			Pipe & Tubes for Pressure Vessels	...	...	...	B274-53T
5052	GR20A	201	Plate & Sheet	QQ-A-318b	...	4015C 4016C 4017C	B209-54T
			Plate & Sheet for Pressure Vessels	...	...	...	B178-53T
			Bar, Rod, Wire & Shapes; Rolled or Drawn	QQ-A-315a-1	...	4114A	B211-53T
			Tubes; Drawn	WW-T-787a	...	4070D	B210-54T
			Tubes; Hydraulic	WW-T-787a	...	4071D	...
			Pipe & Tubes for Pressure Vessels	...	...	...	B274-53T
5154	GR40A	...	Plate & Sheet	...	MIL-A-17357-1	...	...
			Plate & Sheet for Pressure Vessels	...	...	...	B178-53T
			Bar, Rod & Shapes for Pressure Vessels	...	...	...	B273-53T
			Pipe & Tubes for Pressure Vessels	...	...	...	B274-53T
			Welding Rod	...	MIL-E-16053C	...	...
2011	CP60A	...	Bar, Rod & Wire; Rolled or Drawn	QQ-A-365	...	...	B211-53T

TABLE A2-5: ALUMINUM MILL PRODUCT SPECIFICATIONS (Continued)

ALLOY NUMBER AA 1	ASTM 2	SAE 3	PRODUCT 4	ALLOY SPECIFICATIONS FEDERAL 5	MILITARY 6	AMS 7	ASTM 8
2014	CS41A	260	Bar, Rod, Wire & Shapes; Rolled or Drawn	QQ-A-266	...	4121A	B211-53T
			Bar, Rod & Shapes; Extruded	QQ-A-261		4153A	B221-53T
			Bar, Rod & Shapes for Pressure Vessels	...	...	...	B273-53T
			Tubes, Extruded	...	...	...	B235-53T
			Pipe & Tubes for Pressure Vessels	...	...	...	B274-53T
			Forgings & Forging Stock	QQ-A-367c-2		4134A 4135G	...
Alclad 2014	Clad CS41A	260	Plate & Sheet	QQ-A-255	...	...	...
2017	CM41A	26	Bar, Rod, Wire & Shapes; Rolled or Drawn	QQ-A-351c	...	4118B	B211-53T
			Rivet Wire	...	MIL-W-7986	...	...
			Rivets	...	MIL-R-5674A-1	...	...
			Forgings & Forging Stock	QQ-A-367c-2	...	...	...
2024	CG42A	24	Plate & Sheet	QQ-A-355b	...	4035C 4037C 4120C	B209-53T
			Bar, Rod, Wire & Shapes; Rolled or Drawn	QQ-A-268	...	...	B211-53T
			Bar, Rod & Shapes; Extruded	QQ-A-267-1	...	4152E	B221-53T
			Bar, Rod & Shapes for Pressure Vessels	...	...	...	B273-53T
			Tubes, Drawn	WW-T-785a	...	4087A 4088C	B210-54T
			Tubes, Extruded	...	...	...	B235-53T
			Tubes; Hydraulic	...	...	4086C	...
			Pipe & Tubes for Pressure Vessels	...	...	...	B274-53T
			Rivet Wire	...	MIL-W-7986	...	...
			Rivets	...	MIL-R-5674A-1	...	...

TABLE A2-5: ALUMINUM MILL PRODUCT SPECIFICATIONS (Continued)

ALLOY NUMBER			PRODUCT	ALLOY SPECIFICATIONS			
AA 1	ASTM 2	SAE 3	4	FEDERAL 5	MILITARY 6	AMS 7	ASTM 8
Alclad 2024	Clad CG42A	240	Plate & Sheet	QQ-A-362a-1	. . .	4040C 40041C 4042C	B209-54T
6053	GS11B	282	Bar, Rod & Shapes; Extruded	. . .	. . .	. . .	B221-53T
			Rivet Wire	. . .	MIL-R-1150A-1	. . .	. . .
			Rivets	. . .	MIL-R-1150A-1	. . .	. . .
6061	GS11A	281	Plate & Sheet	QQ-A-327a-1	. . .	4025B 4026B 4027B	B209-54T
			Plate & Sheet for Pressure Vessels	. . .	. . .	. . .	B178-53T
			Bar, Rod, Wire & Shapes; Rolled or Drawn	QQ-A-325a-1	. . .	. . .	B211-53T
			Bar, Rod & Shapes; Extruded	QQ-A-270-1	. . .	4150B	B221-53T
			Bar, Rod & Shapes for Pressure Vessels	. . .	. . .	. . .	B273-53T
			Tubes; Drawn	WW-T-789a-1	. . .	4080D 4082D	. . .
			Tubes; Hydraulic	WW-T-789a-1	MIL-T-7081-2	4081 4083C	. . .
			Pipe	. . .	. . .	. . .	B241-53T
			Pipe & Tubes for Pressure Vessels	. . .	. . .	. . .	B274-53T
			Forgings and Forging Stock	QQ-A-367c-2	. . .	4127	. . .
			Rivet Wire	. . .	MIL-R-1150A-1	. . .	. . .
			Rivets	. . .	MIL-R-1150A-1	. . .	. . .
Alclad 6061	Clad GS11A	. . .	Plate & Sheet	. . .	. . .	4021A 4022A 4023A	. . .
			Plate & Sheet for Pressure Vessels	. . .	. . .	. . .	B178-53T
6063	GS10A	. . .	Bar, Rod & Shapes; Extruded	. . .	. . .	4156A	B221-53T
			Tubes; Extruded	. . .	*AXS 1752	. . .	B235-53T

TABLE A2-5: ALUMINUM MILL PRODUCT SPECIFICATIONS (Concluded)

ALLOY NUMBER			PRODUCT	ALLOY SPECIFICATIONS			
AA 1	ASTM 2	SAE 3	4	FEDERAL 5	MILITARY 6	AMS 7	ASTM 8
6063	GS10A	...	Pipe	...	...	...	B241-53T
			Pipe & Tubes for Pressure Vessels	...	...	...	B274-53T
7075	ZG62A	...	Plate & Sheet	QQ-A-283-1	...	4044A 4045A	B209-53T
			Bar, Rod, Wire & Shapes; Rolled or Drawn	QQ-A-282	...	4122B	B211-53T
			Bar, Rod & Shapes; Extruded	QQ-A-277	...	4154D	B221-53T
			Tubes; Extruded	...	...	...	B235-53T
			Forgings & Forging Stock	QQ-A-367c-2	...	4139E	...
			Impact Extrusions & Stock	...	...	4170	...
Alclad 7075	Clad ZG62A		Plate & Sheet	QQ-A-287-1	...	4048A 4049A	B209-52T
			Tapered Plate & Sheet	...	...	4047	...

TABLE A2-6: ALUMINUM INGOT & CASTING SPECIFICATIONS

ALLOY NUMBER			ALLOY SPECIFICATIONS			
COMMERCIAL 1	ASTM 2	SAE 3	FEDERAL 4	MILITARY 5	AMS 6	ASTM 7
INGOT, FOUNDRY						
43	S5A,B,C	35,304	QQ-A-371b	...	...	B179-53T
214	G4A	320	QQ-A-371b	...	...	B179-53T
A214	GZ42A	...		...	...	B179-53T
B214	GS42A	...	...	...	...	B179-53T
356	SG70A	323	QQ-A-371b	...	...	B179-53T
SAND CASTINGS						
43	S5A	35	QQ-A-601a	MIL-A-17129-1	...	B26-54T
214	GZ42A	320	QQ-A-601a	MIL-A-17129-1	...	...
B214	GS42A	...	...		...	B26-54T
356	SG70A	323	QQ-A-601a	MIL-A-17129-1	4217B	...
PERMANENT MOLD CASTINGS						
43	S5A,B	35	QQ-A-596a-1	MIL-A-958A	...	B108-54T
A214	GZ42A	...	QQ-A-596a-1	...	...	B108-54T

TABLE A2-6: ALUMINUM INGOT & CASTING SPECIFICATIONS (Concluded)

ALLOY NUMBER			ALLOY SPECIFICATIONS			
COMMERCIAL 1	ASTM 2	SAE 3	FEDERAL 4	MILITARY 5	AMS 6	ASTM 7
B214	GS42A	...	...	...	...	B108-54T
356	SG70A	323	QQ-A-596a-1	MIL-A-958A	4284B	B108-54T
DIE CASTING						
43	S5C	304	QQ-A-591a-1	MIL-A-15153A	...	B85-54T

TABLE A2-7: COMPARABLE U.S. AND FOREIGN ALLOY DESIGNATIONS*

U.S.A.	CANADA (ALCAN)	GREAT BRITAIN (B.S.)	(B.A.)	(NORAL)	FRANCE (AFNOR)	GERMANY (DIN)	SWITZERLAND (VSM)	ITALY (UNI)
1100	2S	IC	B.A. 99	2S	A4	Al 99	(Hü) Al 99	APO
3003	3S	N...3	B.A. 60	3S	A-M	Al Mn	Al Mn	Pq Al Mn 1.5
4043	33S	N...21		33S	A-S5	S Al Si5		
5052	57S	N...4	B.A. 21	M57S	A-G3	Al Mg3 2.5 Mg	Al 3 Mg	—
2011	28S					(Al Cu Pb Bi)		
2014	26S	H...15	B.A. 303	26S	A-U4SG	(Al Cu Mg[Si])	Al Cu 1 Mg	Pq Al Cu 4.1
2017	17S	H...14	B.A. 301	17S	A-U4G	Al Cu Mg (Normalleg.)	Al Cu 0,5 Mg	Pq Al Cu 3.5
2024	24S				A-U4G1	Al Cu Mg (hochfeste Leg.)	~Al Cu 1 Mg	~Pq Al Cu 4.1
6053	55S					(Al Mg Si)		
6061	65S			65S		(Al Mg Si Cu)		
6063	50S	H...9	B.A. 24	50S	~A-GS	E Al Mg Si	Al Mg Si	Pq Al Si 0.5

* Condensed from Aluminium-Taschenbuch, 1955 by Aluminium-Verlag G.m.b.H.-Düsseldorf, Germany.

Notes to Table A2-7:
When comparing foreign designations with the respective AA numbers, one should bear in mind that the chemical compositions of corresponding alloys are not necessarily identical, but may only be the nearest available in the respective country.

For latest information on data contained in Pages 350 through 366, see American Society of Civil Engineers Journal—Vol. 82 No. ST 3, May 1956, Paper 970.

Proceedings—Vol. 78 May, 1952 Separate No. 132

AMERICAN SOCIETY OF CIVIL ENGINEERS

Founded November 5, 1852

REPORTS

SPECIFICATIONS FOR STRUCTURES OF A MODERATE STRENGTH ALUMINUM ALLOY OF HIGH RESISTANCE TO CORROSION

PROGRESS REPORT OF THE COMMITTEE OF THE STRUCTURAL DIVISION ON DESIGN IN LIGHTWEIGHT STRUCTURAL ALLOYS

Synopsis

These specifications cover allowable stresses, design rules, and fabrication procedures for structures built of the aluminum alloy known commercially as 61S-T6. The basic allowable tensile working stress is 15 kips per sq in. based on a minimum yield strength of 35 kips per sq in. and a minimum tensile strength of 38 kips per sq in.

PART I. GENERAL

Introduction

These specifications cover the allowable stresses, the design rules, and the fabrication procedures for the aluminum alloy most commonly used for structural purposes where a high degree of resistance to corrosion is desired. In the preparation of these specifications the Committee has made use of the available theoretical and experimental work relating to this subject and particularly to the Committee's previously published[1] "Specifications for Heavy Duty Structures of High-Strength Aluminum Alloy."

These specifications are confined to allowable stresses, design rules, and fabrication. No attempt has been made to cover the loading, erection, inspection, or nontechnical provisions included in many specifications, since such provisions are fairly well established in current good structural practice. Furthermore, no attempt has been made to include design rules which cover every detail of construction but rather those which are different from steel

Note.—Please forward all comments on this report directly to E. C. Hartmann, Box 772, New Kensington, Pa.

[1] "Specifications for Heavy Duty Structures of High-Strength Aluminum Alloy," progress report of the Committee of the Structural Division on Design in Lightweight Structural Alloys, *Proceedings Separate No. 22*, Vol. 76, ASCE, June, 1950.

practice or which are needed for the sake of completeness. It is intended, of course, that structures built under these specifications will be designed, constructed, and erected by following the current good practice already well established for steel structures, except as modified herein.

When the abbreviation "kip" is used in these specifications it denotes "kilo"-pounds, or "thousands of pounds."

Material

The principal material considered in these specifications is an aluminum alloy having the following nominal chemical composition:

Composition	Percentage by weight
Copper	0.25
Silicon	0.6
Magnesium	1.0
Chromium	0.25
Aluminum	97.9
Total	100.0

This material is covered by the American Society for Testing Materials (ASTM) Specifications Nos. B221–49T(GS11A), B211–49T(GS11A), B209–50T (GS11A), B247–50T(GS11A), B210–50T(GS11A), B235–50T(GS11A), and B241–50T(GS11A). It is produced by several manufacturers under the commercial designation 61S–T6 and is available in the form of sheet, plate, shapes, tubing, rods, bars, rivets and forgings. All these products are given a solution heat treatment and a precipitation heat treatment before being shipped.

The specified minimum tensile strength of this material is 42 kips per sq in. for all products except extruded shapes and forgings, for which the specified minimum tensile strength is 38 kips per sq in. The specified minimum yield strength for all products is 35 kips per sq in. The following are the lowest of the various specified minimum properties and have been used as a basis for the selection of allowable stresses in these specifications (in kips per square inch):

Description	Stress
Tensile strength	38
Yield strength (offset 0.2%)	35

In addition to the specified minimum tensile properties the engineer will be interested in some of the other mechanical properties not covered by specifications. The following are typical mechanical properties of this alloy:

Shear strength, in kips per square inch	30
Modulus of elasticity in tension and compression, in kips per square inch	10,000
Modulus of elasticity in shear, in kips per square inch	3,800
Poisson's ratio	1/3
Coefficient of expansion per degree Fahrenheit	0.000012
Weight, in pounds per cubic inch	0.098

(The foregoing value of shear strength is typical as determined with steel shearing tools. The value determined by torsion tests is greater.)

Fig. 1 shows tensile and compressive stress-strain curves and the compressive tangent modulus curve for 61S–T6 material having the minimum properties listed in the second paragraph of this section.

Alloy 61S–T6 is the one principally considered in the preparation of these specifications and the one to which the allowable stresses for parts other than bolts apply. However, these specifications may be applied to structures built of other suitable aluminum alloys, provided such alloys meet the specified

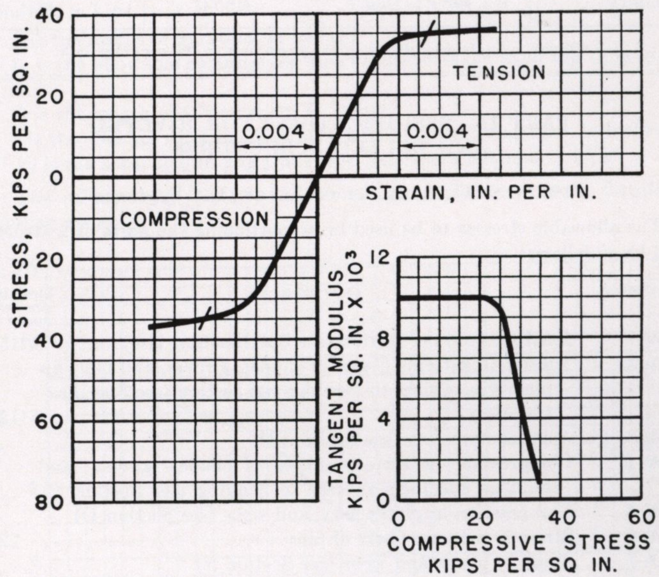


Fig. 1.—Stress-Strain Curves and Tangent Modulus Curve for Alloy 61S-T6 Based on Minimum Properties

strengths and elongations listed in the ASTM specifications mentioned in the first paragraph of this section. Whether or not such other alloys need paint protection will depend upon whether they are as resistant to corrosion as 61S–T6. The sections of this specification dealing with welding should not be applied to other alloys unless it has been clearly demonstrated that such alloys are suitable for welding.

Rivets used in fabricating structures designed in accordance with these specifications shall be of alluminum alloy and may be either cold driven or hot driven. The alloy used is indicated in Table 1. Supplementary informa-

tion on riveting was published[2] by E. C. Hartmann, M. ASCE, G. O. Hoglund, and M. A. Miller in 1944.

Permanent bolts used in structures designed in accordance with these specifications shall be of the aluminum alloy known commercially as 24S–T4. Such bolts have a specified minimum ultimate shear strength of 37 kips per sq in.

TABLE 1.—Alloys to be Used for Rivets

Designation before driving	Driving procedure	Designation after driving	Typical shear strength[a]
61S-T6..........	Cold, as received	61S-T6	30
61S-T4..........	Hot, 990° F to 1,050° F	61S-T43	24

[a] Typical ultimate shear strength of the driven rivet, in kips per square inch.

PART II. SPECIFICATIONS FOR RIVETED AND BOLTED STRUCTURES

Section A. Summary of Allowable Stresses

The allowable stresses to be used in proportioning the parts of a structure shall be as follows:

Specification	Description	Stress in kips per square inch
A-1	Axial tension, net section (see Specification H-4)........	15
A-2	Tension in extreme fibers, of shapes, girders, and built-up members subject to bending, net section (see Specification H-4)..	15
A-3	Axial compression (see Section B).....................	..
A-4	Compression in extreme fibers of shapes, girders, and built-up members subject to bending (see Section C)	..
A-5	Compression in plates, legs, and webs (see Section D)...	..
A-6	Stress in extreme fibers of pins.......................	22
A-7	Shear in plates and webs (see Section E)................	..
A-8	Shear in aluminum alloy 61S–T6 rivets, cold driven (see Tables 4 and 5)...................................	10
A-9	Shear in aluminum alloy 61S–T43 rivets, driven at temperatures of from 990° F to 1,050° F (see Tables 4 and 6)	8
A-10	Shear in turned bolts of aluminum alloy 24S–T4 in reamed holes (see Table 4).............................	12
A-11	Shear in pins..	10
A-12	Bearing on pins...	22
A-13	Bearing on hot-driven or cold-driven rivets, milled stiffeners, turned bolts in reamed holes, and other parts in fixed contact (see Section G).......................	27

[2] "Joining Aluminum Alloys," by E. C. Hartmann, G. O. Hoglund, and M. A. Miller, *Steel*, August 7, 1944, p. 84.

Section B. Column Design

B–1. Allowable Compressive Stress in Columns.—The allowable compressive stress on the gross section of axially loaded columns shall be determined from the curves in Fig. 2. Let k be a factor describing end restraint. Ordinarily the curve for partial restraint ($k = 0.75$) shall be used. The curves for pin-ended and fixed-ended columns, also shown in Fig. 2, may be used as a guide in the selection of allowable compressive stresses for those cases in which the degree of end restraint is known to be different from that represented by $k = 0.75$. It is important, however, that no allowable stresses higher than those given for the case of $k = 0.75$ be used in actual design unless a detailed analysis of the structure demonstrates convincingly that a value of k smaller than 0.75 is justified for the member in question.

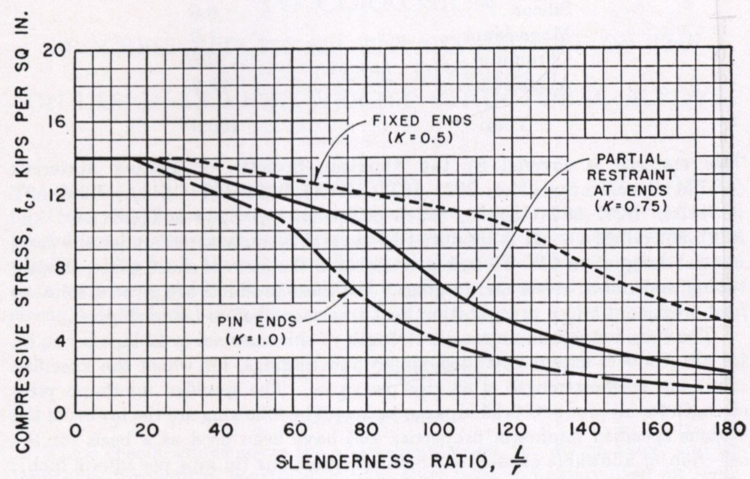


Fig. 2.—Allowable Compressive Stresses for Axially Loaded Columns (Gross Section)

Columns having cross sections involving webs and outstanding legs of such proportions that local buckling may control the design shall be checked by the method outlined in Section D.

B–2. Maximum Slenderness Ratio.—The ratio of unsupported length to least radius of gyration for compression members shall not exceed 120.

B–3. Connections.—Compression members shall be so designed that the main elements of the section will be connected directly to the gusset plates, pins, or other members.

B–4. Compression Splices.—Members designed for compression, if faced for bearing, shall be spliced on four sides sufficiently to hold the abutting parts true to place. The splice shall be as near a panel point as practicable and shall be designed to transmit at least one half of the stress through the splice

material. Members not faced for bearing shall be fully spliced for the computed stress. In either case, adequate provision shall be made for transmitting shear.

B–5. Stay Plates.—On the open sides of compression members, the flanges shall be connected by lacing bars, and there shall be stay plates as near each end as practicable. There shall be stay plates at intermediate points where the lacing is interrupted. In main members the length of the end stay plates shall not be less than one and one-fourth times the distance between rivet lines. The thickness of stay plates shall not be less than one fortieth of the distance between rivet lines.

B–6. Diagonal Lacing.—The slenderness ratio of the part of the flange between the lacing bar connections shall be not more than two thirds of the slenderness ratio of the member.

B–7. Combined Compression and Bending.—The allowable bending stress in a member which carries bending moment in addition to uniform compression (as, for example, an eccentrically loaded column) shall be determined from one of the following two formulas—whichever gives the lower value:

a. Failure by Bending in Plane of Bending Forces.—The maximum bending stress (compression) which may be permitted at or near the center of the unsupported length, in addition to uniform compression, P/A, equals

$$f_b = \left(f_1 - \frac{P}{A}\right)\left(1 - \frac{P/A}{f_{Cp}}\right) \quad \text{(1)}$$

in which (in kips per square inch):

P/A is the average compressive stress on the gross cross section, A, of a member, produced by a column load, P;

f_1 is the compressive stress taken from Figs. 4, 5, or 6 for a member when considered as a beam, and

f_{Cp} is the allowable compressive working stress for a member considered as an axially loaded column tending to fail in the plane of the bending forces.

b. Failure by Buckling Normal to Plane of Bending Forces.—The maximum bending stress (compression) which may be permitted at or near the center of the unsupported length, in addition to the uniform compression, P/A, equals

$$f_b = f_B\left(1 - \frac{P/A}{f_{Cn}}\right)\left(1 - \frac{P/A}{f_{CE}}\right) \quad \text{(2)}$$

in which (in kips per square inch): f_B is the allowable compressive working stress for a member considered as a beam; f_{Cn} is the allowable working stress for a member considered as an axially loaded column tending to fail in a direction normal to the plane of the bending forces; and

$$f_{CE} = \frac{70000}{(L/r)^2}$$

in which L/r is the slenderness ratio for a member considered as a column tending to fail in the plane of the bending forces.

B–8. Transverse Shear in Columns.—In designing lacing or shear webs for columns, the maximum shear on the column shall be computed from the formula:

$$V = P\,\frac{4.5r^2\,(f_B - P/A)}{f_C\,L\,c} + V_t \quad \text{(3a)}$$

but shall not be taken less than

$$V = 0.02\,P + V_t \quad \text{(3b)}$$

in which:

V is the maximum transverse shear on any transverse section of a column in the outer eighth of the length at each end, in the direction of assumed bending, in kips;

r is the radius of gyration, in inches;

f_C is the allowable compressive working stress taken from Fig. 2, in kips per sq in.;

L is the length of the member, in inches;

c is the distance from the centroidal axis to the extreme fiber, in inches; and

V_t is the shear due to any transverse loads on a column, in kips.

The values of f_B, f_C, L, r, and c must be consistent with the direction of bending assumed.

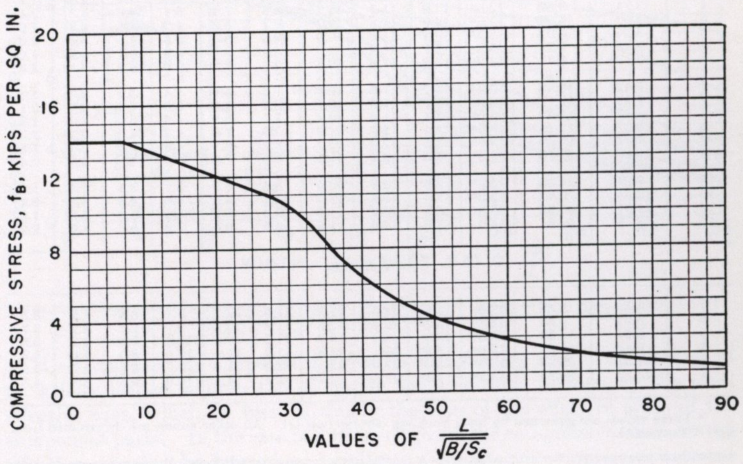


Fig. 3.—Allowable Compressive Stresses in Beam and Girder Flanges (Gross Section)

Section C. Allowable Compressive Stresses in Flanges of Beams and Girders

C–1.—The allowable compressive stress in the extreme fiber (gross section) of single-web rolled shapes, extruded shapes, girders, and built-up sections, subject to bending, shall be determined from the curve in Fig. 3. The terms used in Fig. 3 are defined as follows:

L is the laterally unsupported length of compression flange (clear distance between supports at which the beam is prevented from lateral displacement) in inches;

TABLE 2.—Allowable Compressive Stress in Beam Flanges for Various Values of Laterally Unsupported Length of Compression Flange, L, in Inches

Procedure.—Maximum allowable bending moments are found by multiplying the allowable compressive stresses (in kips per square inch) by the gross section modulus of the beam. The stress on the net section of the tension flange must also be kept within allowable limits.

Depth (in.)	Weight (lb per ft)	Section modulus (in.^{3})	Values of L									
			16	32	64	96	128	160	192	256	352	480
			(a) I-Beams									
2	0.804	0.481	13.1[a]	12.1	9.4	5.8	4.2	3.3	2.7	2.0	1.4	. . .
2	1.473	0.782	13.7	12.7	11.4	10.4	8.6	6.8	5.7	4.2	3.1	2.3
2.5	1.850	1.162	13.8	12.9	11.9	11.1	10.3	9.0	7.5	5.6	4.1	3.0
3	2.02	1.68	13.8	12.7	11.1	9.5	7.1	5.6	4.6	3.5	2.5	1.8
3	2.67	1.95	13.9	12.9	11.7	10.8	9.5	7.8	6.5	4.8	3.5	2.6
4	2.72	3.03	13.9	12.8	11.1	9.1	6.6	5.2	4.3	3.1	2.3	1.7
4	3.74	3.59	13.9[a]	13.0	11.7	10.7	9.3	7.4	6.1	4.6	3.3	2.4
5	3.53	4.90	13.9[a]	12.9	11.2	9.3	6.7	5.2	4.2	3.1	2.3	1.6
5	5.25	6.09	13.9[a]	13.2	11.9	10.9	9.8	8.0	6.6	4.9	3.6	2.6
6	4.43	7.36	13.9[a]	13.1	11.4	9.6	6.9	5.3	4.3	3.1	2.3	1.6
6	6.13	8.77	13.9[a]	13.2	11.8	10.7	9.1	7.2	5.9	4.4	3.1	2.3
7	5.42	10.48	13.9[a]	13.2	11.6	10.0	7.2	5.5	4.4	3.2	2.3	1.6
7	7.12	12.12	13.9[a]	13.3	11.8	10.7	8.8	6.8	5.6	4.1	2.9	2.1
8	6.53	14.39	13.9[a]	13.4	11.8	10.4	7.7	5.8	4.6	3.3	2.4	1.7
8	9.07	17.18	13.9[a]	13.4	12.0	11.0	9.6	7.6	6.2	4.5	3.2	2.3
9	7.72	19.09	13.9[a]	13.5	12.0	10.7	8.2	6.1	4.9	3.5	2.4	1.8
9	10.68	22.75	13.9[a]	13.5	12.2	11.1	9.8	7.8	6.3	4.6	3.3	2.4
10	9.01	24.68	13.9[a]	13.6	12.1	10.9	8.8	6.5	5.1	3.6	2.5	1.8
10	12.45	29.41	13.9[a]	13.6	12.3	11.2	10.1	8.2	6.6	4.8	3.4	2.4
12	11.31	36.35	13.9[a]	13.6	12.2	11.0	9.2	6.7	5.2	3.6	2.5	1.8
12	17.78	50.81	14.0	13.8	12.6	11.6	10.8	9.6	7.9	5.6	4.0	2.9
			(b) H-Beams									
4	4.85	5.36	13.8[a]	13.6	12.5	11.6	11.0	10.2	9.1	6.8	4.9	3.5
5	6.63	9.53	13.7[a]	13.7[a]	12.8	12.0	11.3	10.6	9.7	7.2	5.2	3.7
6	8.04	14.69	13.6[a]	13.6[a]	13.1	12.2	11.5	10.9	10.0	7.6	5.3	3.8
6	9.40	15.81	13.6[a]	13.6[a]	13.1	12.3	11.7	11.1	10.5	8.5	6.0	4.3
8	11.51	28.23	13.3[a]	13.3[a]	13.0[a]	12.6[a]	12.0	11.3	10.7	8.6	5.7	3.9
8	13.32	30.23	13.3[a]	13.3[a]	13.0[a]	12.7[a]	12.1	11.5	10.9	9.3	6.4	4.5

[a] These values are governed by local buckling (see Section D). All other values are determined from Fig. 3, Section C.

S_c is the section modulus for the beam about the axis normal to the web (compression side) in inches cubed;

$$B = I_1 \, d \sqrt{11.7 + \frac{J}{I_1}\left(\frac{L}{d}\right)^2};$$

I_1 is the moment of inertia for the beam about the axis parallel to the web, in inches[4];

J is the torsion factor, in inches to the fourth power; and

d is the depth of beam, in inches.

In the case of beams having top and bottom flanges of different lateral stiffness, I_1 should be calculated as if both flanges were the same as the compression flange. Values of the torsion factor J are published for many standard shapes.[3] Values of J for plates and shapes not published may be calculated by assuming the section to be composed of rectangles and taking the sum of the terms $b\,t^3/3$ for each rectangle, in which b equals the length and t, the thickness of the rectangle, both in inches. The value of J for a built-up member is the sum of the individual values of J of the sections of which it is composed.

TABLE 3.—Allowable Compressive Stress in Channel Flanges for Various Values of Laterally Unsupported Length of Compression Flange, L, in Inches

Procedure.—Maximum allowable bending moments are found by multiplying the allowable compressive stresses (in kips per square inch) by the gross section modulus of the beam. The stress on the net section of the tension flange must also be kept within allowable limits.

Depth (in.)	Weight (lb per ft)	Section modulus (in.^{3})	Values of L									
			16	32	64	96	128	160	192	256	352	480
3	1.46	1.10	13.5	12.3	10.6	8.0	5.9	4.7	3.9	2.9	2.1	1.5
3	2.13	1.38	13.7	12.8	11.6	10.6	9.2	7.4	6.1	4.6	3.3	2.4
4	1.90	1.92	13.6	12.3	10.4	7.2	5.2	4.1	3.4	2.5	1.8	1.3
4	2.58	2.29	13.7	12.6	11.1	9.4	7.1	5.6	4.7	3.5	2.5	1.8
5	2.38	3.00	13.7	12.4	10.4	7.0	5.0	3.9	3.2	2.6	1.7	1.3
5	4.09	4.17	13.8[a]	12.9	11.6	10.5	8.9	7.1	5.9	4.4	3.2	2.3
6	2.91	4.37	13.7[a]	12.6	10.6	7.0	5.0	3.8	3.1	2.3	1.7	1.2
6	4.63	5.80	13.8[a]	12.9	11.4	9.9	7.6	6.0	4.9	3.7	2.7	1.9
7	3.47	6.08	13.7[a]	12.8	10.8	7.4	5.1	3.9	3.2	2.3	1.7	1.2
7	6.13	8.64	13.8[a]	13.0	11.6	10.4	8.5	6.7	5.5	4.1	2.9	2.1
8	4.38	8.46	13.8[a]	12.9	11.0	8.0	5.4	4.1	3.3	2.4	1.7	1.3
8	6.99	11.34	13.8[a]	13.1	11.6	10.4	8.2	6.4	5.2	3.9	2.8	2.0
9	4.74	10.60	13.8[a]	13.0	11.2	8.3	5.5	4.1	3.3	2.4	1.7	1.2
9	8.90	15.75	13.8[a]	13.2	11.8	10.7	9.0	7.1	5.8	4.3	3.1	2.2
10	5.43	13.47	13.8[a]	13.1	11.3	8.8	5.8	4.3	3.4	2.4	1.7	1.2
10	10.67	20.69	13.8[a]	13.3	12.0	10.9	9.5	7.6	6.2	4.6	3.3	2.3
12	7.63	21.97	13.8[a]	13.4	11.7	12.0	6.8	5.0	3.9	2.7	1.8	1.4
12	12.45	29.94	13.8[a]	13.5	12.0	10.9	9.2	7.1	5.7	4.1	2.9	2.1

[a] These values are governed by local buckling (see Section D). All other values are determined from Fig. 3, Section C,

The allowable stresses from Fig. 3 provide a safe margin against the lateral buckling type of failure. The outstanding compression flanges of the beams and girders should be checked for local buckling by the method outlined in Section D.

Table 2 lists values of allowable stress determined from Fig. 3 and Section D for various laterally unsupported lengths of a number of standard I-beams and H-beams. Table 3 lists similar values for standard channels.

Because of their tube-like cross section, double-web box girders are very stiff in torsion compared with single-web girders of comparable size, and, hence, lateral buckling failures such as are considered in Fig. 3 do not occur

[3] "Alcoa Structural Handbook," Aluminum Co. of America, Pittsburgh, Pa., 1950, pp. 87–112.

in such girders. For double-web box girders it is necessary only to check for local buckling of the flanges by the method outlined in Section D.

SECTION D. ALLOWABLE COMPRESSIVE STRESS FOR PLATES, LEGS, AND WEBS

D-1.—For struts consisting of a single angle or a T-section the compressive stress on the gross area shall not exceed the values given by the curves in Fig. 4 or Fig. 2, whichever is smaller.

D-2.—For compression members other than those consisting of a single angle or a T-section the following procedure shall be followed to provide a suitable margin of safety against the weakening effects of local buckling of flat plates, legs, and webs:

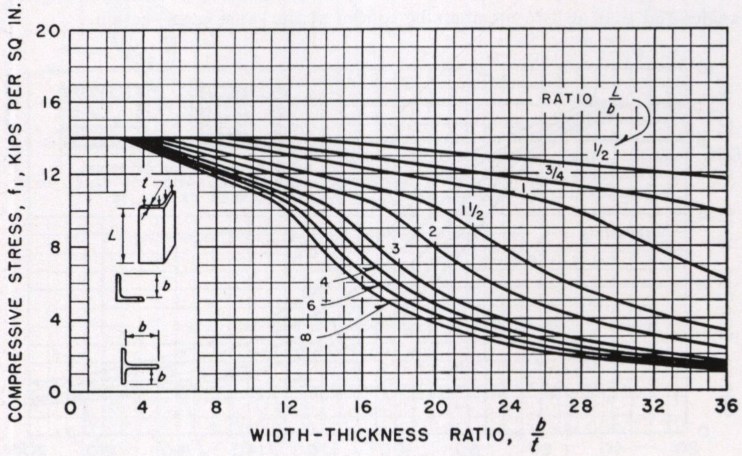


FIG. 4.—ALLOWABLE COMPRESSIVE STRESSES IN OUTSTANDING LEGS OF SINGLE-ANGLE AND T-SECTION STRUTS (GROSS SECTION)

a.—Compute the compressive stress f_c on the flat plate, leg, or web in question, based on the design loads and the gross area, without regard to local buckling. This stress must be within allowable limits as defined in Sections B and C.

b.—Find the limiting value of b/t corresponding to the stress, f_c, by the use of Fig. 5 or Fig. 6. If the flat plate, leg, or web has a ratio of unsupported width to thickness not exceeding this limiting value, local buckling is not a problem and the full gross area of the plate, leg, or web may be considered effective.

c.—If the flat plate, leg, or web has a ratio of unsupported width to thickness greater than the limiting $\frac{b}{t}$-ratio found in step b, only a part of its unsupported width shall be included in computing its effective area. The part of the unsupported width of any individual flat plate, leg, or web which may be considered effective shall be found as follows:

$$b_e = b\frac{f_1}{f_c} \qquad (4)$$

in which:

b_e is that part of the unsupported width considered effective, in inches;
b is the unsupported width, in inches;
f_c is the compressive stress based on gross area from step (*a*), in kips per square inch; and
f_1 is the stress found from Fig. 5 or Fig. 6 corresponding to the $\frac{b}{t}$-value for the plate, leg, or web in question, in kips per square inch.

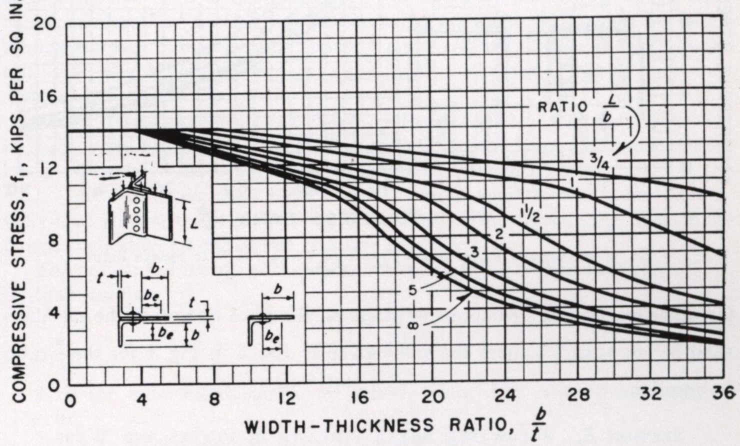


FIG. 5.—CHART FOR DETERMINING EFFECTIVE WIDTH FOR OUTSTANDING LEGS OF ANGLES BUILT INTO OTHER PARTS AND FOR PLATES BUILT IN ALONG ONE EDGE

d.—Compute the compressive stress on the effective area. In the case of an axially loaded column this is simply the axial load divided by the total effective area, which, in turn, is simply the sum of the effective areas of the component parts. In the case of a beam or girder the compressive stress on the effective area shall be determined as follows: Compute the compressive extreme fiber stress f_c for the gross section of the beam or girder and then multiply this value by the ratio of the gross compression flange area to the effective compression flange area, including in both flange areas not only the flange proper but also that part of the web in the outermost one sixth of the over-all depth of the beam or girder.

e.—The compressive stress on the effective area computed in accordance with step d shall not exceed allowable limits as defined in Section B and C for the gross area.

f.—Step c provides a suitable factor of safety against the collapse of the member as a whole but does not necessarily provide complete protection against the local buckling of individual flat surfaces at the design load. Where local buckling at the design load cannot be tolerated because of appearance, or

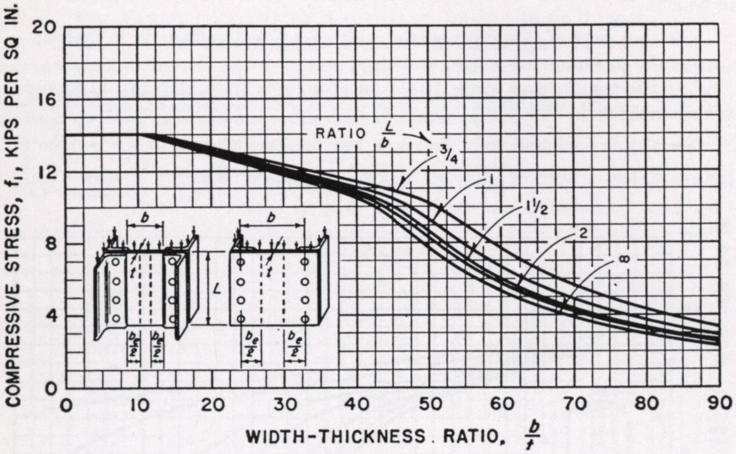


FIG. 6.—CHART FOR DETERMINING EFFECTIVE WIDTH FOR FLAT PLATES BUILT IN ALONG TWO EDGES

for other reasons, th e compressive stress on the gross section of the members shall be less than 1.5 times the value given in Fig. 5 or Fig. 6 for the $\frac{b}{t}$-ratio in question.

SECTION E. ALLOWABLE SHEAR STRESSES IN PLATES AND WEBS

E-1.—The allowable shear stress on flat webs shall not exceed the values given by the curves in Fig. 7. The values in Fig. 7 apply to the gross area of the web, but the shear on the net area shall not exceed 10 kips per sq in.

SECTION F. PLATE GIRDER DESIGN

F-1. Proportioning Plate Girders.—Plate girders shall be proportioned by the moment of inertia method, with the gross section used to determine the moment of inertia.

The stress on the net area of the tension flange shall be found by multiplying the stress on the gross section by the ratio of the gross area of the tension flange to the net area. In determining this ratio the tension flange shall be considered to consist of the flange angles and cover plates plus that part of the web included in the outermost one sixth of the over-all height of the girder.

F-2. Allowable Flange Stress.—The allowable compressive stress in the extreme fiber of plate girders shall be determined as outlined in Sections C and D. The numerical value of the term $\sqrt{B/S_c}$, used in Fig. 3, is rarely less than one half of the width, in inches, of the compression flange for a plate girder. This fact is useful in preliminary design.

F-3. Flange Cover Plates.—Cover plates shall extend far enough to allow at least two extra rivets at each end of the plate beyond the theoretical end, and the spacing of the rivets in the remainder of the plate shall be such as to develop the required strength of the plate at any section.

F-4. Flange Rivets.—The flanges of plate girders shall be connected to the web with enough rivets to transmit the longitudinal shear at any point together with any load that is applied directly on the flange.

F-5. Flange Splices.—It is preferable that flange angles be spliced with angles and that no two members be spliced at the same cross section.

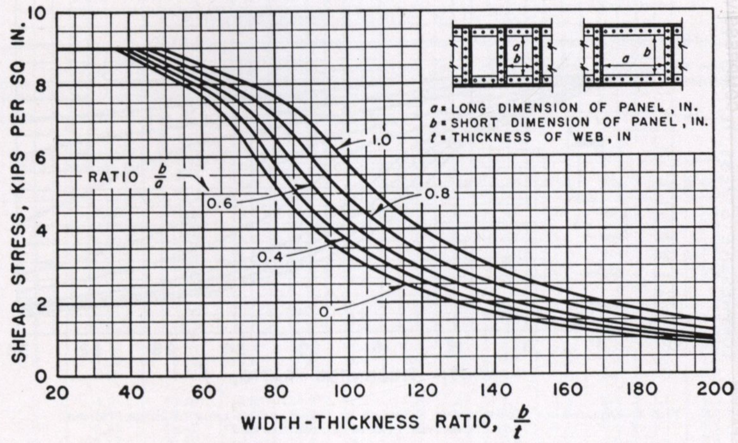


FIG. 7.—ALLOWABLE SHEAR STRESSES ON WEBS; PARTIAL RESTRAINT ASSUMED AT EDGES OF RECTANGULAR PANELS (GROSS SECTION)

F-6. Allowable Web Stresses.—The allowable shear stress in the webs of plate girders shall not exceed the values given by the curves in Fig. 7. The longitudinal compressive stress in webs of plate girders at the toe of the compression flange shall not exceed the values given by the curves in Fig. 8.

F-7. Web Splices.—It is preferable that splices in the webs of plate girders be made with splice plates on both sides of the web.

F-8. Spacing of Vertical Stiffeners to Resist Shear Buckling.—The distance, s, between vertical stiffeners shall not exceed the values given by the solid curves in Fig. 9, which are replots of the curves in Fig. 7. The maximum value of the ratio of stiffener spacing to height of web, s/h, in Fig. 9 shall be determined from the ratio of clear height to thickness, h/t, and the computed shear stress on the girder web. Where a stiffener is composed of a pair of members, one on each side of the web, the distance s shall be the clear distance between the

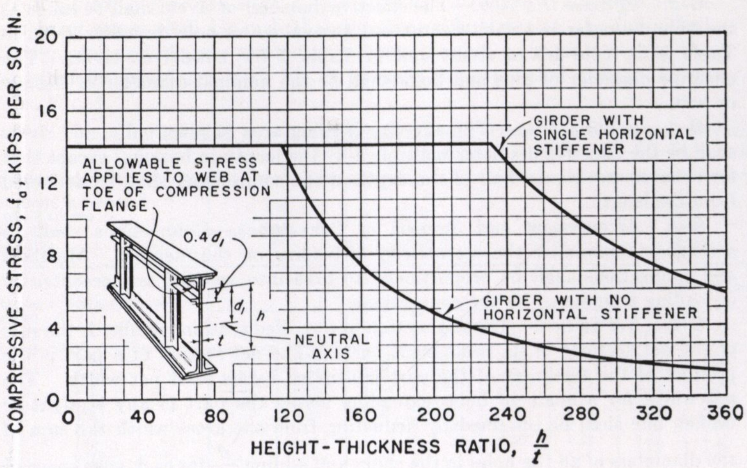


FIG. 8.—ALLOWABLE LONGITUDINAL COMPRESSIVE STRESSES FOR WEBS OF GIRDERS

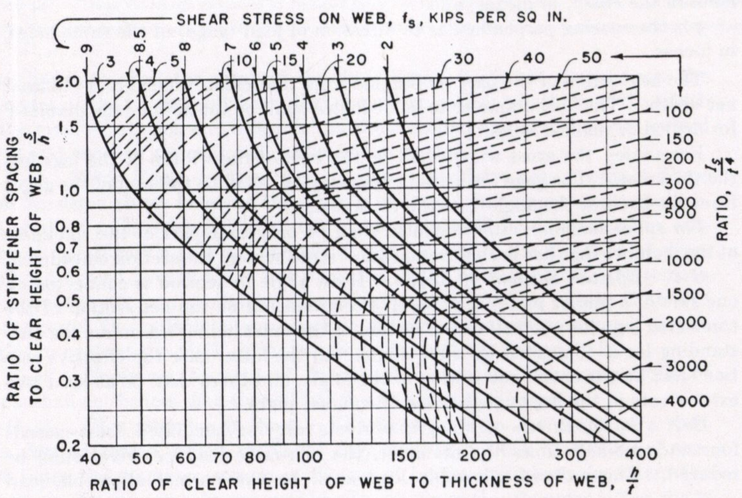


FIG. 9.—SPACING AND MOMENT OF INERTIA OF VERTICAL STIFFENERS TO RESIST SHEAR BUCKLING ON WEBS OF PLATE GIRDERS

stiffeners. Where a stiffener is composed of a member on one side of the web only, the distance s shall be the distance between rivet lines. In determining the spacing of vertical stiffeners to resist shear buckling in panels containing a horizontal stiffener located as shown in Fig. 8, the distance h in Fig. 9 may be taken as 90% of the clear height between flanges.

F–9. Size of Vertical Stiffeners to Resist Shear Buckling.—Stiffeners applied to plate girder webs to resist shear buckling shall have a moment of inertia not less than the values given by the dotted curves in Fig. 9. The minimum value of the ratio of the stiffener moment of inertia to the fourth power of the web thickness, I_s/t^4, in Fig. 9, shall be determined from the ratio of height of web to thickness of web, h/t, and the computed shear stress on the girder web.

For a stiffener composed of members of equal size on both sides of the web, the moment of inertia shall be taken about the center line of the web. For a stiffener composed of a member on one side only, the moment of inertia shall be taken about the face of the web in contact with the stiffener. In determining moment of inertia of stiffeners, the term h shall always be taken as the full clear height between flanges, regardless of whether or not a horizontal stiffener is present.

F–10. Vertical Stiffeners at Points of Bearing.—Stiffeners shall be placed in pairs at end bearings of plate girders and at points of bearing of concentrated loads. They shall be connected to the web by enough rivets to transmit the load. Such stiffeners shall have a close bearing against the loaded flanges. Only that part of the stiffener cross section which lies outside the fillet of the flange angle shall be considered effective in bearing.

The moment of inertia of the stiffener shall not be less than that given by the formula:

$$I = I_s + \frac{P\,h^2}{70{,}000} \quad \text{.......................(5)}$$

in which:

I_s is the moment of inertia, in inches^4, required to resist shear buckling (Fig. 9);

P is a local load concentration on the stiffener, in kips; and

h is the clear height of the web between flanges, in inches.

F–11. Horizontal Stiffeners.—A horizontal stiffener of the type shown in Fig. 8 shall have a moment of inertia not less than that given by the formula:

$$I_h = f\,t\,h^3 \left[\left(16 + 90\,\frac{A_h}{h\,t}\right)\left(\frac{s}{h}\right)^2 + 6\right] \times 10^{-7} \quad \text{.........(6)}$$

in which:

I_h is the moment of inertia of the horizontal stiffener, in inches^4;

h is the clear height of web between flanges, in inches;

t is the thickness of web, in inches;

f is the compressive stress at the toe of the flange angles, in kips per square inch;

s is the distance between vertical stiffeners, in inches; and

A_h is the gross area of cross section of the horizontal stiffener, in square inches.

For a stiffener composed of members of equal size on both sides of the web, the moment of inertia shall be taken about the center line of the web. In the case of a stiffener consisting of a member on one side only, the moment of inertia shall be taken about the face of the web in contact with the stiffener.

Eq. 6 must be solved by trial, since both the moment of inertia, I_h, and the area, A_h, of the stiffener are unknown. It is generally convenient to assume as a first approximation that the ratio $A_h/(h\,t)$ has the value 0.1.

Section G. Riveted and Bolted Connections

G–1. Allowable Loads.—The allowable loads on rivets and bolts shall be calculated using the allowable shear and bearing stresses listed in Section A with the following exceptions:

a.—If a rivet or a bolt is used in relatively thin plates or shapes the allowable shear stress shall be reduced in accordance with the information given[2] in Table 4.

TABLE 4.—Percentage Reduction in Shear Strength of Aluminum Alloy Rivets Resulting from Their Use in Thin Plates and Shapes

Ratio,[a] $\frac{D}{t}$	Loss in double shear[b]	Ratio,[a] $\frac{D}{t}$	Loss in double shear[b]	Ratio,[a] $\frac{D}{t}$	Loss in: Single shear	Loss in: Double shear	Ratio,[a] $\frac{D}{t}$	Loss in: Single shear	Loss in: Double shear
(1)	(3)	(1)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
1.5	0	2.2	9.1	2.9	0	18.2	3.5	2.0	26.0
1.6	1.3	2.3	10.4	3.0	0	19.5	3.6	2.4	27.3
1.7	2.6	2.4	11.7	3.1	0.4	20.8	3.7	2.8	28.6
1.8	3.9	2.5	13.0	3.2	0.8	22.1	3.8	3.2	29.9
1.9	5.2	2.6	14.3	3.3	1.2	23.4	3.9	3.6	31.2
2.0	6.5	2.7	15.6	3.4	1.6	24.7	4.0	4.0	32.5
2.1	7.8	2.8	16.9	....	....	....	....	....	....

[a] Ratio of the rivet diameter, D, to the plate thickness, t. The thickness used is that of the thinnest plate in a single shear joint or of the middle plate in a double shear joint. [b] The percentage loss of strength in single shear is zero for D/t less than 3.0.

b.—If the distance from the center of a rivet or bolt to the edge of a plate or shape toward which the pressure of the rivet or bolt is directed is less than twice the diameter of the rivet or bolt, the allowable bearing stress shall be reduced in accordance with the following:

Ratio of edge distance to rivet or bolt diameter	Allowable bearing stress, in kips per square inch
2 or more	27
$1\frac{3}{4}$	25
$1\frac{1}{2}$	23

The allowable loads calculated for cold-driven 61S–T6 rivets are given in Table 5 and those for 61S–T43, hot-driven rivets, are given in Table 6.

G–2. Effective Diameter.—The effective diameter of rivets shall be taken as the hole diameter but shall not exceed the values of hole diameter given in Table 5 for cold-driven rivets and in Table 6 for hot-driven rivets. The effective diameter of pins and bolts shall be the nominal diameter of the pin or bolt.

G–3. Bearing Area.—The effective bearing area of pins, bolts, and rivets shall be the effective diameter multiplied by the length in bearing; except that for countersunk rivets, half of the depth of the countersink shall be deducted from the length.

G–4. Arrangement and Strength of Connections.—Connections shall be arranged to minimize the eccentricity of loading on the member. Members and connections shall be proportioned to take into account any eccentricity of loading introduced by the connections.

G–5. Net Section.—The net section of a riveted tension member is the sum of the net sections of its component parts. The net section of a part is the product of the thickness of the part multiplied by its least net width. The net width for a chain of holes extending across the part in any straight or broken line shall be obtained by deducting from the gross width the sum of the diameters of all the holes in the chain and adding $\frac{s^2}{4\,g}$ for each gage space in the chain. In the correction quantity $\frac{s^2}{4\,g}$:

s is the spacing parallel to direction of load (pitch) of any two successive holes in the chain, in inches; and

g is the spacing perpendicular to direction of load (gage) of the same holes, in inches.

The net section of the part is obtained from that chain which gives the least net width. The hole diameter to be deducted shall be the actual hole diameter for drilled or reamed holes.

For angles, the gross width shall be the sum of the widths of the legs less the thickness. The gage for holes in opposite legs shall be the sum of the gages from the back of the angle, less the thickness.

For splice members, the thickness shall be only that part of the thickness of the member that has been developed by rivets beyond the section considered.

G–6. Effective Sections of Angles.—If an angle in tension is connected on one side of a gusset plate, the effective section shall be the net section of the connected leg plus one half of the section of the outstanding leg unless the outstanding leg is connected by a lug angle. In the latter case the effective section shall be the entire net section of the angle, and there shall be at least two extra rivets in the lug angle beyond the gusset plate.

G–7. Grip of Rivets.—If the grip of rivets carrying calculated stress exceeds four and one-half times the diameter, the allowable load per rivet shall be reduced. The reduced allowable load shall be the normal allowable load divided by $\left(\frac{1}{2} + \frac{G}{9D}\right)$ in which G is the grip, and D the nominal diameter of the rivet. If the grip exceeds six times the diameter, special care shall be taken in driving the rivets to insure that the holes will be filled completely.

G–8. Pitch of Rivets in Built-Up Compression Members.—The pitch in the direction of stress shall be such that the allowable stress on the individual outside plates and shapes, treated as columns having a length equal to the rivet pitch in accordance with Fig. 2, exceeds the calculated stress. In no case, however, shall the pitch in the direction of stress exceed six times the diameter of the rivets; and for a distance of one and one-half times the width of the member at each end, the pitch in the direction of stress shall not exceed three and one-half times the diameter of the rivets.

G–9. Stitch Rivets.—Where two or more web plates are in contact, there shall be stitch rivets to make them act in unison. In compression members, the pitch of such rivets in the direction of stress shall be determined as outlined in Specification G–8. The gage at right angles to the direction of stress shall not exceed twenty times the thickness of the outside plates. In tension members the maximum pitch or gage of such rivets shall be twenty times the thickness of the outside plates; and in tension members composed of two angles in contact the pitch of the stitch rivets shall not exceed 10 in.

G–10. Minimum Spacing of Rivets.—The distance between centers of rivets shall not be less than three times the diameter of the rivets.

G–11. Edge Distance of Rivets.—The distance from the center of a rivet to a sheared, sawed, rolled, or planed edge shall be not less than one and one-half times the diameter, except in flanges of beams and channels, where the minimum distance may be one and one-fourth times the diameter. For rivets under computed stress, the distance from the center of the rivet to the edge of the plate or shape toward which the pressure of the rivet is directed should normally be at least twice the nominal diameter of the rivet. In cases where a

shorter edge distance must be used, the allowable bearing stress shall be reduced in accordance with Specification G–1, exception *b*.

The distance from the edge of a plate to the nearest rivet line shall not exceed six times the thickness of the plate.

TABLE 5.—ALLOWABLE DESIGN LOAD, IN KIPS PER RIVET, FOR COLD-DRIVEN 61S–T6 RIVETS IN 61S–T6 STRUCTURES (SHEAR, 10 KIPS PER SQ IN.; AND BEARING, 27 KIPS PER SQ IN.[a])

Dimensions, in Inches: Rivet diameter / Hole diameter / Drill size	3/8 / 0.386 / W		7/16 / 0.453 / 29/64		1/2 / 0.516 / 33/64		9/16 / 0.578 / 37/64		5/8 / 0.641 / 41/64		3/4 / 0.766 / 49/64		7/8 / 0.891 / 57/64		1 / 1.016 / 1-1/64		Dimensions, in inches: Rivet diameter / Hole diameter / Drill size
	RIVET IN SINGLE SHEAR (ss) OR IN DOUBLE SHEAR (ds)																
Thickness of plate, or shape, in inches:	ss	ds	ss	ds	ss	ds	ss	ds	ss	ds	ss	ds	ss	ds	ss	ds	Thickness of plate, or shape, in inches:
1/8	1.17	1.30[b]	1.53[b]	1.53[b]	1.74[b]	1.74[b]	1.95[b]	1.95[b]	2.16[b]	2.16[b]	....	....	....	....	....	....	1/8
3/16	1.17	1.95[b]	1.61	2.29[b]	2.09	2.61[b]	2.62	2.93[b]	3.18[c]	3.25[b]	3.88[b]	3.88[b]	4.51[b]	4.51[b]	....	....	3/16
1/4	1.17	2.34	1.61	3.06[b]	2.09	3.48[b]	2.62	3.90[b]	3.23	4.33[b]	4.61	5.17[b]	6.02[b]	6.02[b]	6.86[b]	6.86[b]	1/4
5/16	1.17	2.34	1.61	3.22	2.09	4.13[c]	2.62	4.88[b]	3.23	5.41[b]	4.61	6.46[b]	6.24	7.52[b]	8.04[c]	8.57[b]	5/16
3/8	1.17	2.34	1.61	3.22	2.09	4.18	2.62	5.25	3.23	6.31[c]	4.61	7.76[b]	6.24	9.02[b]	8.11	10.29[b]	3/8
7/16	....	....	1.61	3.22	2.09	4.18	2.62	5.25	3.23	6.45	4.61	8.97[c]	6.24	10.52[b]	8.11	12.00[b]	7/16
1/2	....	....	....	....	2.09	4.18	2.62	5.25	3.23	6.45	4.61	9.22	6.24	12.03[b]	8.11	13.72[b]	1/2
9/16	....	....	....	....	....	....	2.62	5.25	3.23	6.45	4.61	9.22	6.24	12.39[c]	8.11	15.43[b]	9/16
5/8	....	....	....	....	....	....	....	....	3.23	6.45	4.61	9.22	6.24	12.47	8.11	16.00[c]	5/8
3/4	....	....	....	....	....	....	....	....	....	....	4.61	9.22	6.24	12.47	8.11	16.22	3/4
7/8	....	....	....	....	....	....	....	....	....	....	....	....	6.24	12.47	8.11	16.22	7/8
1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	8.11	16.22	1

[a] Assuming distance from center of rivet to edge of member toward which the pressure of the rivet is directed is not less than twice the nominal rivet diameter (see Specification G–1, exception *b*). [b] These values are governed by bearing. [c] These values are governed by reduced shear strengths as indicated in Table 4. All other values are governed by basic allowable shear stress.

G–12. Sizes of Rivets in Angles.—The diameter of the rivets in angles whose size is determined by calculated stress shall not exceed one fourth of the width of the leg in which they are driven. In angles whose size is not so determined, 1-in. rivets may be used in 3½-in. legs; 7/8-in. rivets, in 3-in. legs; and 3/4-in. rivets, in 2½-in. legs.

G–13. Extra Rivets.—If splice plates are not in direct contact with the parts which they connect, there shall be rivets on each side of the joint in excess of the number required in the case of direct contact, to the extent of two extra lines for each intervening plate.

If rivets carrying calculated stress pass through fillers, the fillers shall be extended beyond the connected member and the extension secured by enough additional rivets to distribute the total stress in the member uniformly over the combined section of the member and filler.

SECTION H. MISCELLANEOUS DESIGN RULES

H–1. Reversal of Load.—Members subject to reversal of load under the passage of live load shall be proportioned as follows: Determine the tensile load and the compressive load and increase each by 50% of the smaller; then proportion the member and its connections so that the allowable stresses given in Sections A to G, inclusive, will not be exceeded by either increased load.

H–2. Slenderness Ratio of Tension Members.—The ratio of unsupported length to least radius of gyration for tension members shall not exceed the value given by the following formula:

$$\frac{L}{r} = 150 + 10 f_t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

in which f_t is the lowest net section tensile stress to which the member will be subjected in actual service, in kips per square inch.

H–3. Stay Plates for Tension Members.—Segments of tension members not directly connected to each other shall be stayed together. The length of the stay plate shall be not less than three fourths of the distance between rivet lines of the segments. Stay plates shall be connected to each segment of the tension member by at least three rivets. The distance between stay plates shall be such that the slenderness ratio of the individual segments does not exceed that given by Eq. 7, Specification H–2.

H–4. Fatigue.—Tests indicate that riveted members designed in accordance with the requirements of these specifications and constructed so as to be free from severe reentrant corners and other unusual stress raisers will safely withstand at least 300,000 repetitions of maximum live load without fatigue failure regardless of the ratio of minimum to maximum load. Where a greater number of repetitions of some particular loading cycle is expected during the life of the structure, the calculated net section tensile stresses for the loading in question shall not exceed the values given by the curves in Fig. 10. When using the curves in Fig. 10 the reversal-of-load rule in Specification H–1 should be ignored. The final member and connections selected, however, shall be strong enough to satisfy the requirements of Specification H–1.

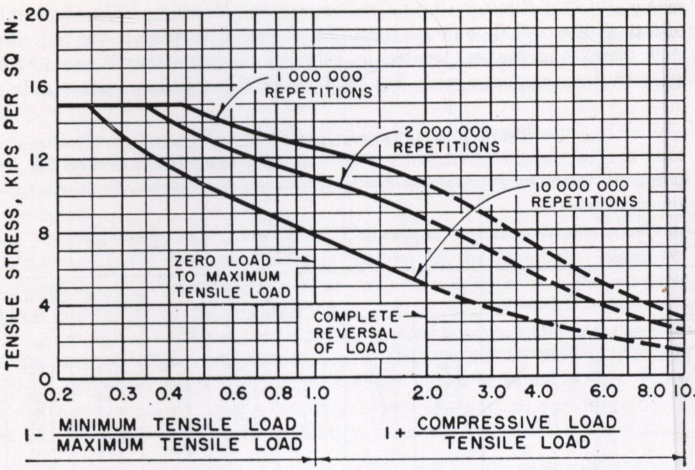


FIG. 10.—ALLOWABLE TENSILE STRESSES ON NET SECTION FOR VARIOUS NUMBERS OF REPETITIONS OF LOAD APPLICATION

TABLE 6.—ALLOWABLE DESIGN LOADS, IN KIPS PER RIVET, FOR HOT-DRIVEN 61S–T43 RIVETS IN 61S–T6 STRUCTURES (RIVETS DRIVEN AT 990° F TO 1,050° F; SHEAR, 8 KIPS PER SQ IN.; AND BEARING, 27 KIPS PER SQ IN.[a])

Dimensions, in inches: Rivet diameter / Hole diameter / Drill size	3/8 0.397 X		7/16 0.469 15/32		1/2 0.531 17/32		9/16 0.594 19/32		5/8 0.656 21/32		3/4 0.781 25/32		7/8 0.922 59/64		1 1.063 1-1/16		Dimensions, in Inches: Rivet diameter / Hole diameter / Drill size
	Rivet in Single Shear (ss) or in Double Shear (ds)																
Thickness of plate, or shape, in inches:	ss	ds	ss	ds	ss	ds	ss	ds	ss	ds	ss	ds	ss	ds	ss	ds	Thickness of plate, or shape, in inches:
1/8	0.99	1.34[b]	1.35[c]	1.58[b]	1.70[c]	1.79[b]	2.00[c]	2.00[b]	2.21[b]	2.21[b]	....	....	....	....	....	....	1/8
3/16	0.99	1.85[c]	1.38	2.37[b]	1.77	2.69[b]	2.22	3.01[b]	2.66[c]	3.32[b]	3.68[c]	3.95[b]	4.67[b]	4.67[b]	....	....	3/16
1/4	0.99	1.98	1.38	2.68[c]	1.77	3.31[c]	2.22	4.00[c]	2.70	4.43[b]	3.83	5.27[b]	5.23[c]	6.22[b]	6.82[c]	7.18[b]	1/4
5/16	0.99	1.98	1.38	2.76	1.77	3.50[c]	2.22	4.26[c]	2.70	5.06[c]	3.83	6.59[b]	5.34	7.78[b]	7.04[c]	8.97[b]	5/16
3/8	0.99	1.98	1.38	2.76	1.77	3.54	2.22	4.43	2.70	5.29[c]	3.83	7.17[c]	5.34	9.34[b]	7.10	10.76[b]	3/8
7/16	....	....	1.38	2.76	1.77	3.54	2.22	4.43	2.70	5.41	3.83	7.46[c]	5.34	9.99[c]	7.10	12.56[b]	7/16
1/2	....	....	....	....	1.77	3.54	2.22	4.43	2.70	5.41	3.83	7.67	5.34	10.34[c]	7.10	13.28[c]	1/2
9/16	....	....	....	....	....	....	2.22	4.43	2.70	5.41	3.83	7.67	5.34	10.61[c]	7.10	13.69[c]	9/16
5/8	....	....	....	....	....	....	....	....	2.70	5.41	3.83	7.67	5.34	10.68	7.10	14.02[c]	5/8
3/4	....	....	....	....	....	....	....	....	....	....	3.83	7.67	5.34	10.68	7.10	14.20	3/4
7/8	....	....	....	....	....	....	....	....	....	....	....	....	5.34	10.68	7.10	14.20	7/8
1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	7.10	14.20	1

[a] Assuming distance from center of rivet to edge of member toward which the pressure of the rivet is directed is not less than twice the nominal rivet diameter (see Specification G–1, exception *b*). [b] These values are governed by bearing. [c] These values are governed by reduced shear strengths as indicated in Table 4. All other values are governed by basic allowable shear stress.

In considering fatigue action on structures it is well to bear in mind the following points:

a.—The most severe combination of loadings for which a structure is designed (dead load, maximum live load, maximum impact, maximum wind, etc.)

rarely occurs in actual service and is of little or no interest from the standpoint of fatigue.

b.—The loading of most interest from the fatigue standpoint is the steady dead load with a superimposed and repeatedly applied live load having an intensity consistent with day to day normal operating conditions.

c.—The number of cycles of load encountered in structures is usually small compared with those encountered in fatigue problems involving machine parts. It takes many years of service to accumulate even 300,000 cycles of any significant stress application in most structures as is indicated by the following examples: 300,000 cycles represent 30 cycles every day for 27 years; 10,000,000 cycles represent 20 cycles every hour for 57 years. Care must be taken not to overestimate grossly the number of cycles for any given load condition.

d.—Careful attention to details in design and fabrication pays big dividends in fatigue life. When a fatigue failure occurs in a structure it is usually at a point of stress concentration where the state of stress could have been improved with little or no added expense.

Section I. Fabrication

I-1. Laying Out.—

a.—Hole centers may be center punched and cutoff lines may be punched or scribed. Center punching and scribing shall not be used where such marks would remain on fabricated material.

b.—A temperature correction shall be applied where necessary in the layout of critical dimensions. The coefficient of expansion shall be taken as 0.000012 per degree Fahrenheit.

I-2. Cutting.—

a.—Material 1/2 in. thick or less may be sheared, sawed, or cut with a router. Material more than 1/2 in. thick shall be sawed or routed.

b.—Cut edges shall be true and smooth, and free from excessive burrs or ragged breaks.

c.—Edges of plates carrying calculated stresses shall be planed to a depth of 1/4 in. except in the case of sawed or routed edges of a quality equivalent to a planed edge.

d.—Reentrant cuts shall be avoided wherever possible. If used they shall be filleted by drilling prior to cutting.

e.—Flame cutting of aluminum alloys is not permitted.

I-3. Heating.—Structural material shall not be heated, with the following exceptions:

a.—Material may be heated to a temperature not exceeding 400° F for a period not exceeding 30 min to facilitate bending. Such heating shall be done only when proper temperature controls and supervision are provided to insure that the limitations on temperature and time are carefully observed.

b.—Hot-driven rivets shall be heated as specified in Section I-5.

I-4. Punching, Drilling, and Reaming.—Rules for punching, drilling, and reaming are as follows:

a.—Rivet or bolt holes in main members shall be subpunched or subdrilled and reamed to finished size after the parts are firmly bolted together. The amount by which the diameter of a subpunched hole is less than that of the finished hole shall be at least $\frac{1}{4}$ the thickness of the piece and in no case less than $\frac{1}{32}$ in. If the metal thickness is greater than the diameter of the hole punching shall not be used.

b.—Rivet or bolt holes in secondary material not carrying calculated stress may be punched or drilled to finished size before assembly.

c.—The finished diameter of holes for cold-driven rivets shall be not more than 4% greater than the nominal diameter of the rivet.

d.—The finished diameter of holes for hot-driven rivets shall be not more than 7% greater than the nominal diameter of the rivet.

e.—The finished diameter of holes for unfinished bolts shall be not more than 1/16 in. larger than the nominal bolt diameter.

f.—Holes for turned bolts shall be drilled or reamed to give a driving fit.

g.—All holes shall be cylindrical and perpendicular to the principal surface. Holes shall not be drifted in such a manner as to distort the metal. All chips lodged between contacting surfaces shall be removed before assembly.

I-5. Riveting.—

a.—The driven head of aluminum alloy rivets preferably shall be of the flat or the cone-point type, with dimensions as follows:

(1) Flat heads shall have a diameter not less than 1.4 times the nominal rivet diameter and a height not less than 0.4 times the nominal rivet diameter.

(2) Cone-point heads shall have a diameter not less than 1.4 times the nominal rivet diameter and a height, to the apex of the cone, not less than 0.65 times the nominal rivet diameter. The included angle at the apex of the cone shall be approximately 127°.

b.—Rivets shall be driven hot or cold as called for on the plans, provision for heating being as follows:

(1) Hot-driven rivets shall be heated in a hot air type furnace providing uniform temperatures throughout the rivet chamber and equipped with automatic temperature controls.

(2) Hot-driven rivets shall be held at from 990° F to 1,050° F for not less than 15 min and for not more than 1 hour before driving.

(3) Hot rivets shall be transferred from the furnace to the work and driven with a minimum loss of time.

c.—Rivets shall fill the holes completely. Rivet heads shall be concentric with the rivet holes and shall be in proper contact with the surface of the metal.

d.—Defective rivets shall be removed by drilling.

I-6. Painting.—

a.—Structures of the alloy covered by these Specifications are not ordinarily painted except where the aluminum alloy parts are in contact with, or are fastened to, steel members or other dissimilar materials. At such locations the aluminum shall be kept from direct contact with the steel or other dissimilar material by painting the aluminum surface with one coat of zinc chromate primer in accordance with United States Navy Department Specification 52P18 or the equivalent, or with one coat of suitable aluminum pigmented caulking compound (brushing consistency with chromate pigment added). Zinc chromate paint shall be allowed to dry before assembly of the parts. The steel or other dissimilar material shall be painted with a good quality priming paint suitable to the material.

b.—Aluminum surfaces to be placed in contact with concrete or masonry construction shall, before installation, be given a heavy coat of an alkali-resistant bituminous paint. The quality of the bituminous paint used shall be equal to that called for in the Army-Navy Aeronautical Specification AN–P–31. The paint shall be applied as it is received from the manufacturer without the addition of any thinner.

c.—Although structures of the alloy covered by these specifications are not ordinarily painted, there may be applications where the structures are to be exposed to extremely corrosive conditions which make over-all painting advisable. In such instances all contacting metal surfaces shall be painted before assembly with one coat of zinc chromate primer in accordance with United States Navy Department Specification 52P18 or the equivalent, or with one coat of suitable aluminum pigmented caulking compound (brushing consistency with chromate pigment added). Zinc chromate paint shall be allowed to dry before assembly of the parts. All other surfaces shall be given one shop coat of zinc chromate primer made in accordance with Navy Department Specification 52P18, or one giving equivalent performance, and then shall be given a second shop coat of paint consisting of 2 lb of aluminum paste pigment (ASTM Specification D962–48T, Type II, Class A) per gallon of varnish meeting Federal Specification TTV81a, Type II, or the equivalent. Sufficient Prussian blue shall be added to permit detection of an incomplete application of the subsequent paint coat. After erection, bare spots shall be touched up with zinc chromate primer followed by a touch-up coat of aluminum paint as specified above. The completed structure shall be finished according to one of the following methods:

(1) One field coat of aluminum paint as specified above, except that Prussian blue shall be omitted from the field coat.

(2) One or more field coats of alkyd base enamel pigmented to meet a desired color scheme.

I-7. Cleaning and Treatment of Metal Surfaces.—All surfaces to be painted shall be cleaned as follows:

a.—Surfaces of metal shall be cleaned immediately before painting by a method which will remove all dirt, oil, grease, chips, and other foreign substances.

b.—Either of the two following methods of cleaning may be used on exposed metal surfaces:

(1) Chemical Cleaning.—Parts may be immersed in, or swabbed with, a solution of phosphoric acid and organic solvents diluted with water in the ratio of 1:3. The solution temperature shall be between 50° F and 90° F. The solution shall remain in contact with the metal not less than 5 min. Residual solution shall be removed with clear water.

(2) Sandblasting.—Standard mild sandblasting methods may be used on sections more than 1/8 in. thick.

c.—For contacting surfaces only, the metal may be cleaned in accordance with Specification I–7b, or with a solvent such as mineral spirits or benzine.

d.—Flame cleaning is not permitted.

PART III. SPECIFICATIONS FOR WELDED STRUCTURES

Section J. Allowable Stresses for Welded Parts

Although the strength of alloy 61S–T6 is lowered locally by the heat of welding, its resistance to corrosion is not impaired and excellent results can be obtained. Welded members of alloy 61S–T6 are proportioned in accordance with the general rules of Section II except that it is necessary to lower the allowable stresses in the heat affected zone as indicated by the following supplementary rules:

J-1. The basic allowable stress in tension is found from curve B in Fig. 11.

J-2. The basic allowable stress in bearing against rivets, milled stiffeners turned bolts in reamed holes and other parts in fixed contact is found from curve A in Fig. 11.

J-3. Allowable compressive stresses are found from Figs. 2, 3, 4, 5, 6, and 8 in the usual manner except that a horizontal cutoff line is drawn at a stress value found from curve C of Fig. 11 and all values above this cutoff line are ignored.

J-4. Allowable shear stresses are taken from Fig. 7 in the usual manner except that a horizontal cutoff line is drawn at a stress value found from curve D of Fig. 11 and all values above this cutoff line are ignored.

J-5. Fillet welds shall be designed using an allowable shear stress on the throat of the weld of 4 kips per sq in.

Section K. Miscellaneous Design Rules

K-1. Fatigue tests indicate that welded members designed in accordance with the requirements of these specifications and constructed so as to be free from severe re-entrant corners and other unusual stress raisers, will safely withstand at least 10,000 repetitions of maximum live load without fatigue failure regardless of the ratio of minimum to maximum load. For greater numbers of cycles present indications are that the maximum tensile stresses at the welds should be held to about one-fourth those shown in Fig. 10, with a horizontal cutoff line drawn at 8 kips per sq in. At locations other than at the welds the allowable tensile stresses may be selected from Fig. 10 with a horizontal cutoff line drawn at a stress value found from curve B of Fig. 11.

The general comments on fatigue action in structures in Specification H–4 are applicable to welded members.

Section L. Fabrication

L–1. General.—These specifications are proposed for application to both field and shop welding operations. The general recommendations and regula-

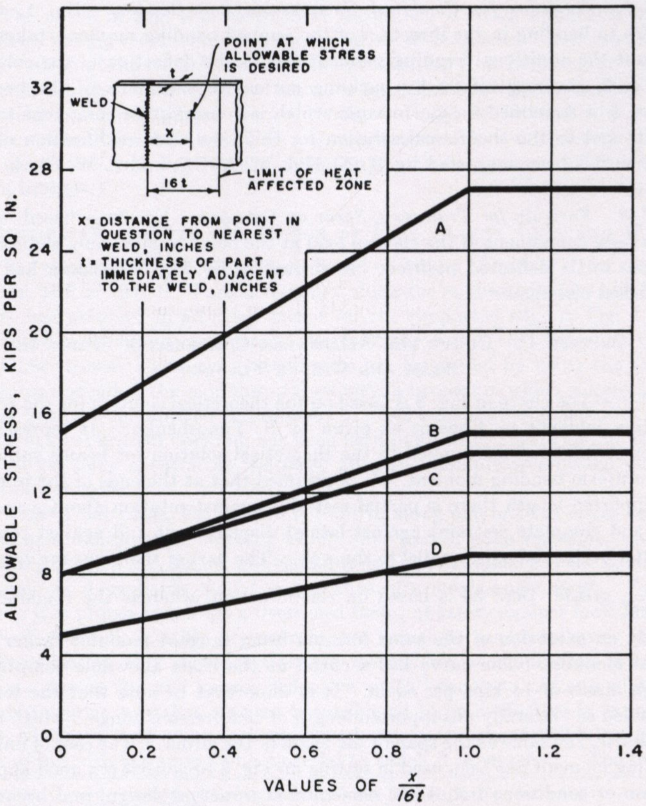


Fig. 11.—Allowable Stresses in Welded Parts

tions shown in the American Welding Society Specifications D2.0–47 "Welded Highway and Railway Bridges" 1947 and D1.0–46 "Code for Arc and Gas Welding in Building Construction" 1946 apply as well to welded 61S–T6 structures. Detail requirements in the above specifications apply only to steel structures. Detail requirements for welding alloy 61S–T6 are given in the following paragraphs.

L–2. Preparation for Welding.—Dirt, grease, forming or machining lubricants or any organic materials shall be removed from the areas to be welded by cleaning with a suitable solvent or by vapor degreasing.

Additional operations to remove the oxide coating just prior to welding are required when the inert gas tungsten arc welding method is used. This may be done by etching or by scratch brushing. The oxide coating may not need to be removed if the welding is done with the automatic or semi-automatic inert gas shielded metal arc.

Suitable edge preparation to ensure 100% penetration in butt welds shall be used. Flame cutting shall not be used. Sawing, chipping, machining or shearing may be used.

L–3. Welding Procedure.—Parts shall be welded with an arc or resistance welding process. No welding process that requires the use of a welding flux shall be used. The filler metal shall be aluminum alloy 43S or other approved alloy capable of meeting the qualification test requirements. Preheating for welding is permissible provided the temperature does not exceed 400° F for a total time of 30 min.

L–4. Qualification of Welding Procedure and Welding Operator.—The welding process and welding operators shall both meet a qualification test. The method of qualification shall be mutually agreed upon between the inspecting agency and the contractor or shall conform to the method described in the American Welding Society Specification B3.0-41T "Standard Qualification Procedure." Aluminum alloy 61S–T6 shall be used as the material for qualification test plates.

The minimum requirements for test results in kips per sq in. shall be as follows:

Test	Stress
(a) Reduced Section Tensile Test	22
(b) Longitudinal Shear Test	13
(c) Transverse Shear Test	13

Elongation in the free bend test shall not be less than 8 per cent.

In addition to the above types of tests, root, face, side-bend and fillet weld soundness tests shall be made. The specimens shall be considered as having passed these tests if (1) no cracks or other open defect exceeding 1/8 in. measured in any direction is present in the weld metal or between the weld and base material after the bending, or (2) the specimen has cracked or fractured and the fracture surface shows complete penetration through the entire thickness of the weld, and absence of inclusions and porosity to the extent that there are no gas pockets or inclusions exceeding 1/16 in. in greatest dimension, and the sum of the greatest dimensions of all such defects in any square inch of weld metal area does not exceed 3/8 in. (If necessary, the specimen shall be broken apart to permit examination of the fracture.)

L–5. Rewelding Defects.—Portions of joints that have been rejected on inspection because of defects may be repaired only by rewelding. The defective area shall be removed by chipping or machining. Flame cutting shall not be used. Before rewelding, the joint shall be inspected to insure that all of the

defective weld has been removed and that the joint is accessible so that the welding operator can obtain full penetration through the joint.

PART IV. EXPLANATION OF SPECIFICATIONS

Section A. Summary of Allowable Stresses

A–1. Basic Tensile Design Stress.—The basic tensile design stress of 15 kips per sq in. represents a factor of safety of 2.33 based on the specified tensile yield strength. This is a larger factor of safety with respect to yield strength than is ordinarily encountered in specifications for structural steel. In selecting this rather large factor of safety on yield strength, the committee was influenced to a considerable extent by the fact that there is a smaller spread between yield strength and tensile strength in this aluminum alloy than is commonly encountered in structural steels.

A–8, A–9, and A–13. Allowable Stresses on Rivets.—The allowable shearing and bearing stresses on rivets were selected on the basis of the results of numerous shearing and bearing tests. The factors of safety used are greater than those used for most of the other allowable stresses.

A–6, A–11, and A–12. Allowable Stresses in Pins.—The allowable bending, shearing, and bearing stresses on pins were selected to bear about the same relation to the corresponding properties of the material as is the case in standard steel specifications. It is not anticipated that any wide use of pins will be made in aluminum alloy structures but it is assumed that where they are used they will be of the same material as the structural members themselves, and that they would probably be obtained in the form of rolled rod, ASTM Specification B211–49T (GS11A).

Section B. Column Design

B–1. Curves for Allowable Compressive Stresses in Axially Loaded Columns.—The curves in Fig. 2 are the tangent-modulus column curves with a factor of safety of 2.5 and with a cut-off at the basic allowable compressive design stress of 14 kips per sq in. The formulas for all three curves can be written[4,5]

$$f_C = \frac{\pi^2 E_t}{2.5\left(\frac{k\,L}{r}\right)^2} \qquad (8)$$

in which:

f_C is the allowable compressive stress on the gross cross-sectional area in kips per square inch;

E_t is the tangent modulus taken from Fig. 1 at stress corresponding to $2.5(f_C)$, in kips per square inch;

L is the length of the column, in inches;

r is the least radius of gyration of the column, in inches; and

k is a factor describing the end conditions as defined in Fig. 2.

[4] "Column Strength of Various Aluminum Alloys," by R. L. Templin, R. G. Sturm, E. C. Hartmann, and M. Holt, *Aluminum Research Laboratories Technical Paper No. 1*, Aluminum Co. of America, Pittsburgh, Pa., 1938.

[5] "Inelastic Column Theory," by F. R. Shanley, *Journal of the Aeronautical Sciences*, Vol. 14, 1947, pp. 261–268.

For values of slenderness ratio, L/r, greater than 91, the formula for the partial restraint curve in Fig. 2 reduces to

$$f_C = \frac{70{,}000}{\left(\frac{L}{r}\right)^2} \qquad (9)$$

B–7. Formulas for Combined Compression and Bending.—Eq. 1, which applies to bending in the direction of the applied bending moment, takes into account the additional bending moment due to the deflection of the column.[6]

Eq. 2, covering failure by buckling normal to the plane of the bending forces, is a simplified design formula which is conservative compared to test results and to the theoretical solution for this case.[7] A modification of this solution has been suggested by H. N. Hill, M. ASCE, and J. W. Clark, Jun. ASCE.[8]

B–8. Formula for Transverse Shear on Columns.—Eq. 3*a* is based on the transverse component of the column load at the point of maximum slope of the column in its deflected position. A derivation by Mr. Hartmann has been published elsewhere.[6]

Section C. Curve for Allowable Compressive Stress in Beam and Girder Flanges

C–1.—The curve in Fig. 3 is based on the theoretical solution for the critical bending moment in I-beams as given by S. Timoshenko.[9] It represents a factor of safety of 2.5 applied to the theoretical solution for beams subjected to a uniform bending moment. It is assumed that at the ends of the laterally unsupported length there is partial restraint against rotation about a vertical axis and complete restraint against lateral displacement and against rotation about a horizontal axis parallel to the web. The part of the curve for values of $\frac{L}{\sqrt{B/S_c}}$ greater than 35 is based on elastic action, whereas the remainder is simply an extension of the same formula using tangent modulus rather than initial modulus. The curve has a cutoff at the basic allowable compressive design stress of 14 kips per sq in. It is important to note that the term L is defined as "laterally unsupported length of compression flange," which is not necessarily the same as the span of the beam or the girder. The case of uniform bending moment has been used in setting up Fig. 3 because it is a good approximation of conditions frequently encountered in actual design, and because it is somewhat more conservative than many of the other cases that might have been selected.

[6] Discussion by E. C. Hartmann of "Rational Design of Steel Columns," by D. H. Young, *Transactions*, ASCE, Vol. 101, 1936, pp. 475–481.

[7] "Torsional and Flexural Buckling of Bars of Thin-Walled Open Section Under Compressive and Bending Loads," by J. N. Goodier, *Transactions*, A.S.M.E., Vol. 64, 1942, pp. A-103–A-107.

[8] "Lateral Buckling of Eccentrically Loaded I-Section and H-Section Columns," by H. N. Hill and J. W. Clark (publication pending).

[9] "Theory of Elastic Stability," by S. Timoshenko, McGraw-Hill Book Co., Inc., New York, N. Y., 1936.

For values of $\frac{L}{\sqrt{B/S_c}}$ greater than 35 the curve in Fig. 3 may be represented by the formula:

$$f_B = \frac{10{,}300}{\left(\frac{L}{\sqrt{B/S_c}}\right)^2} \quad \ldots\ldots (10)$$

The curve in Fig. 3 is based on a theoretical solution applicable only to I-beams having cross sections symmetrical about both axes. The modified interpretation of the term I_1 indicated in Specification *C*–1, however, permits the curve to be used without serious error for beams and girders having one flange differing in lateral stiffness from the other. It should be used with caution in cases of beams and girders which are unsymmetrical by a considerable margin. (In connection with this subject several supplementary references[7,10,11,12,13] will be of interest.)

Section D. Curves for Design of Flat Plates, Legs and Webs

The curves of Figs. 4, 5 and 6 are based on values of critical stress compiled by Mr. Hill in 1940.[14] Partial restraint along the supported edges and loaded edges was assumed in all cases except for the supported edge in Fig. 4 which was considered simply supported. Parts of the curves that represent critical buckling stresses above the elastic range are computed by using the tangent modulus instead of the modulus of elasticity, a procedure which is known to be conservative when applied to problems of plate buckling.[15] A factor of safety of 2.5 against critical buckling has been used in all three charts and in all cases the curves have a cutoff at the basic allowable compressive design stress of 14 kips per sq in.

When a flat plate, leg, or web is built in along one or both edges to other parts of a compression member which offer partial edge restraint, the local buckling of the plate, leg, or web does not precipitate collapse of the member as a whole as it probably would in the case of a single-angle strut. For this reason it is proper to permit a decreased factor of safety against local buckling in such cases if suitable precautions are taken to avoid collapse. Step c of Specification *D–2* provides a simple method for accomplishing this result by introducing the well known "effective width" concept. After a plate, leg, or web buckles, a part of its area is considered to be ineffective in supporting load, whereas a strip along each supported edge is considered still fully effective in working with the supporting material to which it is attached. The formula (Eq. 4) for effective width used in step c of Specification D–2 is generally more conservative than other accepted methods of computing effective width.[16,17,18,19]

Section E. Curves for Allowable Shear Stress in Webs

E–1.—The values of allowable stress in Fig. 7 are obtained by applying a factor of safety of 2 to the critical shear buckling stresses for flat plates with the edges about half way between the fixed and hinged conditions.[9,20,21]

Those parts of the curves of Fig. 7 which represent critical buckling stresses above the elastic stress range are computed from formulas for elastic buckling with the tangent modulus substituted for the modulus of elasticity. For a given value of critical shear stress, the tangent modulus is that corresponding to an axial stress equal to $\sqrt{3}$ times the shear stress.[22] As in the case of compressive buckling of flat plates, the tangent modulus is conservative.

For values of allowable stress below 6 kips per sq in., the curves of Fig. 7 may be represented by the formula:

$$f_v = \frac{33{,}000}{(b/t)^2}\left[1 + 0.75\left(\frac{b}{a}\right)^2\right] \quad \ldots\ldots (11)$$

Section F. Plate Girder Design

F–6. Curves for Allowable Longitudinal Compressive Stress in Webs of Girders.—The curve in Fig. 8 for girders with no horizontal stiffeners is based on the critical buckling stress for rectangular flat plates under pure bending in the plane of the plate. Partial restraint is assumed at the toes of the flanges (about half way between the solution given by Mr. Timoshenko for the case of a plate simply supported on all four edges[9] and the solution of K. Nolke for a plate with the loaded edges simply supported and the other two edges fixed.[23]

The curve in Fig. 8 for girders with a single horizontal stiffener is based on the critical buckling stress given by Mr. Timoshenko for plates simply supported on all four edges under combined bending and axial stress in the plane of the plate.[9] The simple support condition is used for this case because the horizontal stiffener would provide comparatively little restraint against rotation. The location of the horizontal stiffener shown in the sketch in Fig. 8 is chosen so that the parts of the plate above and below the stiffener will buckle at approximately the same load.

---

[10] "The Lateral Instability of Unsymmetrical I-Beams," by H. N. Hill, *Journal of the Aeronautical Sciences*, Vol. 9, 1942, pp. 175–180.

[11] "The Lateral Stability of Equal-Flanged Aluminum-Alloy I-Beams Subjected to Pure Bending," by C. Dumont and H. N. Hill, *Technical Note No. 770*, National Advisory Committee for Aeronautics, Washington, D. C., 1940.

[12] "Lateral Stability of Unsymmetrical I-Beams and Trusses in Bending," by George Winter, *Transactions*, ASCE, Vol. 108, 1943, pp. 247–268.

[13] "Strength of Beams as Determined by Lateral Buckling," by Karl de Vries, *ibid.*, Vol. 112, 1947, pp. 1245–1320.

[14] "Chart for Critical Compressive Stress of Flat Rectangular Plates," by H. N. Hill, *Technical Note No. 773*, National Advisory Committee for Aeronautics, Washington, D. C., 1940.

[15] "Determination of Plate Compressive Strengths," by George J. Heimerl, *Technical Note No. 1480*, National Advisory Committee for Aeronautics, Washington, D. C., 1947.

[16] "The Strength of Thin Plates in Compression," by Theodor von Kármán, Ernest E. Sechler, and L. H. Donnell, *Transactions*, A.S.M.E., Vol. 54, 1932, pp. 53–57.

[17] "The Apparent Width of the Plate in Compression," by Karl Marguerre, *Technical Memorandum No. 833*, National Advisory Committee for Aeronautics, Washington, D. C., 1937.

[18] "Strength of Thin Steel Compression Flanges," by George Winter, *Transactions*, ASCE, Vol. 112, 1947, pp. 527–576.

[19] "Performance of Thin Steel Compression Flanges," by George Winter, preliminary publication, 3d Cong. of the International Assn. for Bridge and Structural Engrs., Liege, Belgium, 1948.

[20] "Formulas for Stress and Strain," by Raymond J. Roark, McGraw-Hill Book Co., Inc., New York, N. Y., 1938.

[21] "Observations on the Behavior of Aluminum Alloy Test Girders," by R. L. Moore, *Transactions*, ASCE, Vol. 112, 1947, pp. 901–920.

[22] "Critical Shear Stress of an Infinitely Long Plate in the Plastic Region," by Elbridge Z. Stowell, *Technical Note No. 1681*, National Advisory Committee for Aeronautics, Washington, D. C., 1948.

[23] "Buckling of Webs in Deep Steel I-Girders," by Georg Wastlund and Sten G. A. Bergman, rept. of investigation made at the Royal Inst. of Technology, Stockholm, Sweden, 1947.

A factor of safety against buckling of 1.5 was used for the curves of Fig. 8. Although this factor of safety is not as large as some used elsewhere in these specifications, it is considered adequate in this instance since tests have shown that the critical bending stress for girder webs may be considerably exceeded without affecting the load carrying capacity of the girder.[21,23] Use of Fig. 8, however, will prevent buckling from occurring at design stresses.

The curves of Fig. 8 may be represented by the following formulas: No horizontal stiffener—

$$f_a = \frac{190{,}000}{\left(\frac{h}{t}\right)^2} \quad \ldots\ldots (12a)$$

and single horizontal stiffener—

$$f_a = \frac{750{,}000}{\left(\frac{h}{t}\right)^2} \quad \ldots\ldots (12b)$$

The curves are cut off at the basic allowable compressive design stress of 14 kips per sq in.

F–8 and F–9. Curves for Spacing and Moment of Inertia of Vertical Stiffeners.—The curves for determining stiffener spacing, in Fig. 9, are merely replots of the data of Fig. 7. The curves of I_s/t^4 in Fig. 9 represent the following formula:

$$I_s = 8 \times 10^{-5} \times \frac{f_s\, h^3\, t\, (s/h)}{1 + 5\,(s/h)^3} \quad \ldots\ldots (13)$$

in which f_s is the average shear stress on the web in kips per sq in. Eq. 13 is designed to fit the theoretical solution of M. Stein and R. W. Fralich[24] for values of s/h between 0.2 and 1.0. This solution does not cover values of s/h greater than 1.0. In this range, however, Eq. 13 is conservative in comparison with the recommendations of L. S. Moisseiff.[25]

F–10. Formula for Moment of Inertia of Stiffeners at Points of Bearings.—Eq. 5 simply states that the moment of inertia of a stiffener at a point of bearing should be equal to the sum of the moment of inertia required to resist the tendency of the web to buckle and the moment of inertia required for the stiffener to carry the bearing load as a column with length equal to the height of the web.

F–11. Formula for Moment of Inertia of Horizontal Stiffeners.—Eq. 6, for the moment of inertia of horizontal stiffeners, is based on the theoretical work of C. Dubas, reported by F. Bleich.[26]

Section H. Miscellaneous Design Rules

H–2. Formula for Slenderness Ratio of Tension Members.—Eq. 8 is designed to yield slenderness ratios in agreement with values generally accepted for tension members, at the same time taking into account the fact that the higher the minimum tensile stress on the member the less tendency there will be for the member to bend or sway.

H–4. Curves of Allowable Tensile Stress on Net Section for Various Numbers of Repetitions of Load Application.—The curves in Fig. 10 are plotted from the results of fatigue tests conducted at the Aluminum Research Laboratories of the Aluminum Company of America at New Kensington, Pa., on 61S–T6 butt joints with double straps joined with eight cold-driven 5/8-in. 61ST–T6 rivets. The type of testing equipment and specimen (Type M1) used are illustrated in a paper by R. L. Templin[27] M. ASCE, in 1939, and a paper by E. C. Hartmann, J. O. Lyst, and H. J. Andrews,[28] Jun. ASCE, in 1944.

A factor of safety of 1.2 has been applied to the test data and all curves are cut off at the basic allowable tensile design stress of 15 kips per sq in. The right-hand part of the diagram is largely based on extrapolation of the data, but this is not considered to be a serious matter since the design of most members in this range will be governed primarily by Specification H–1 rather than by fatigue considerations.

Section J. Allowable Stresses for Welded Parts

The heat of welding lowers the strength of 61S–T6 parts by an amount that depends on how much heat is applied to the metal in making the weld. Tests of various 61S–T6 welded assemblies, including tests across butt welded joints, have shown that the tensile strength measured in the welded areas, may vary from about 22 kips per sq in. up to values approaching that of the fully heat-treated parent metal. Therefore, it has been assumed that, for design purposes, the minimum tensile strength of the material in the heat-affected zones may be taken as 22 kips per sq in. The corresponding minimum yield strength and shear strength for design purposes have been selected as 15 kips per sq in. and 13 kips per sq in., respectively. The specifications permit higher stresses to be used as the distance from the weld increases because this is consistent with the findings of actual tests on welded parts.

Respectfully submitted,

F. Baron	C. N. Gaylord	J. S. Newell
J. W. Clark	I. G. Hedrick, Jr.	F. L. Plummer
R. Ebenbach	S. A. Kilpatrick	E. J. de Ridder
J. T. Ellis	R. B. B. Moorman	F. J. Tamanini

E. C. Hartmann, *Chairman*
Committee of the Structural Division on Design in Lightweight Structural Alloys

June 13, 1951

[24] "Critical Shear Stress of Infinitely Long, Simply Supported Plate with Transverse Stiffeners," by Manuel Stein and Robert W. Fralich, *Technical Note No. 1851*, National Advisory Committee for Aeronautics, Washington, D. C., 1949.

[25] "Design Specifications for Bridges and Structures of Aluminum Alloy 27S–T," by Leon S. Moisseiff, Aluminum Company of America, Pittsburgh, Pa., 1940.

[26] "Buckling Strength of Metal Structures," by Friedrich Bleich, McGraw-Hill Book Co., Inc., New York, N. Y., 1952.

[27] "Fatigue Machines for Testing Structural Units," by R. L. Templin, *Proceedings*, A.S.T.M., Vol. 39, 1939, pp. 711–722.

[28] "Fatigue Tests of Riveted Joints," by E. C. Hartmann, J. O. Lyst, and H. J. Andrews, *Wartime Report W55*, National Advisory Committee for Aeronautics, Washington, D. C., 1944.

AMERICAN SOCIETY OF CIVIL ENGINEERS

Founded November 5, 1852

TRANSACTIONS

Paper No. 2532

SPECIFICATIONS FOR HEAVY DUTY STRUCTURES OF HIGH-STRENGTH ALUMINUM ALLOY

FINAL REPORT OF THE COMMITTEE OF THE STRUCTURAL DIVISION ON DESIGN IN LIGHTWEIGHT STRUCTURAL ALLOYS

Synopsis

These specifications cover allowable stresses, design rules, and fabrication procedures for riveted heavy duty structures built of the high-strength aluminum alloy known commercially as 14S–T6. The basic allowable tensile working stress is 22 kips per sq in. based on a minimum yield strength of 53 kips per sq in. and a minimum tensile strength of 60 kips per sq in.

PART I. GENERAL

Introduction

These specifications cover the allowable stresses, the design rules, and the fabrication procedures for structures built of the high-strength aluminum alloy most commonly used for heavy duty structural purposes. In the preparation of these specifications the Committee has made use of the available theoretical and experimental work relating to this subject and especially to previous specifications by O. H. Ammann, Shortridge Hardesty, and the late Leon S. Moisseiff,[1] Members, ASCE.

These specifications are confined to allowable stresses, design rules, and fabrication. No attempt has been made to cover the loading, erection, inspection, or nontechnical provisions included in many specifications, since such provisions are fairly well established in current good structural practice. Furthermore, no attempt has been made to include design rules which cover every detail of construction but rather those which are different from steel practice or which are needed for the sake of completeness. It is intended, of

Note.—Published as *Proceedings-Separate No. 22* in June, 1950.

[1] "Design Specifications for Bridges and Structures of Aluminum Alloy 27S-T," by Leon S. Moisseiff, Aluminum Co. of America, Pittsburgh, Pa., 1946.

course, that structures built under these specifications will be designed, constructed, and erected by following the current good practice already well established for steel structures, except as modified herein.

Material

The principal material considered in these specifications is a high-strength aluminum alloy having the following nominal chemical composition:

Composition	Percentage by weight
Copper	4.4
Silicon	0.8
Manganese	0.8
Magnesium	0.4
Aluminum	93.6
Total	100.0

This material is covered by the American Society for Testing Materials (ASTM) Specifications Nos. B221–49T(CS41A), B235–50T(CS41A), B211–49T(CS41A), B247–50T(CS41A), and B209–50T (Clad CS41A). It is produced by several manufacturers under the commercial designation 14S–T6 and is available in the form of shapes, tubes, rods, bars, and forgings. It is also produced in the form of sheet and plate covered on both surfaces with an integral coating, or "cladding," of a corrosion-resistant aluminum alloy. In the latter form it is identified commercially by the designations, Alclad 14S–T6 and R–301. All these products are given a solution heat treatment and a precipitation heat treatment before being shipped.

The specified minimum tensile properties of this material are not the same in all the various products (plate, shapes, etc.). The specified minimum tensile strengths vary from 60 kips per sq in. to 68 kips per sq in., and the specified minimum yield strengths vary from 53 kips per sq in. to 58 kips per sq in. The following are the lowest of the various specified minimum properties and have been used as a basis for the selection of allowable stresses in these specifications (in kips per square inch):

Description	Stress
Tensile strength	60
Yield strength (offset 0.2%)	53

In addition to the specified minimum tensile properties, the engineer will be interested in some of the other mechanical properties not covered by specifications. The following are typical mechanical properties of this alloy and may be considered applicable to "nonclad" products, such as shapes, and to "clad" plate:

Shear strength, in kips per square inch	41
Modulus of elasticity in tension and compression, in kips per square inch	10,600
Modulus of elasticity in shear, in kips per square inch	4,000
Poisson's ratio	1/3
Coefficient of expansion per degree Fahrenheit	0.000012
Weight, in pounds per cubic inch	0.101

(The foregoing value of shear strength is typical as determined with steel shearing tools. The value determined by torsion tests is greater.)

Fig. 1 shows tensile and compressive stress-strain curves and the compressive tangent modulus curve for 14S–T6 material having the minimum properties listed in the second paragraph of this section.

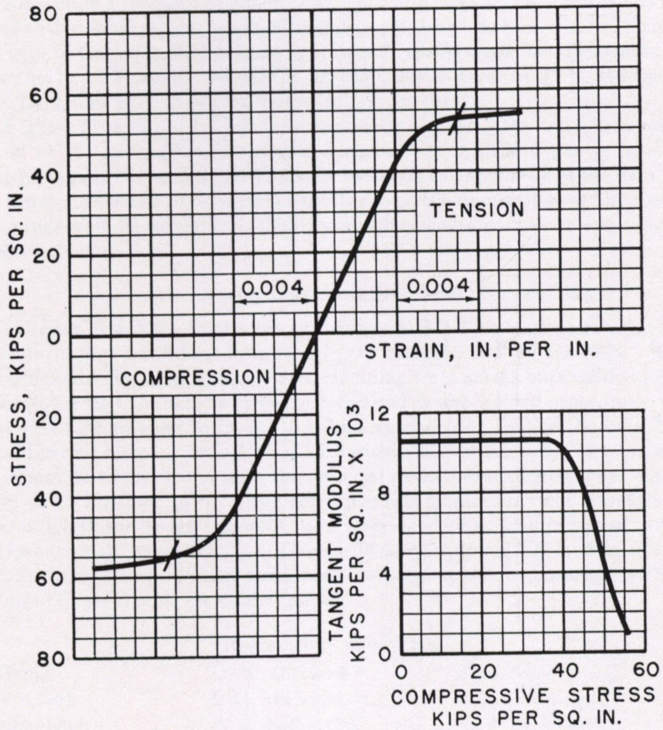


Fig. 1.—Stress Strain and Tangent Modulus Curves

Alloy 14S–T6 is the one principally considered in the preparation of these specifications and the one to which the allowable stresses for parts other than rivets and bolts apply. However, these specifications may be applied to structures built of other suitable aluminum alloys, provided such alloys meet the specified strengths and elongations listed in the ASTM specifications mentioned in the first paragraph of this section.

Rivets used in fabricating structures designed in accordance with these specifications shall be of aluminum alloy and may be either cold driven or

hot driven. The alloys used are indicated in Table 1. Supplementary information on riveting was published[2] by E. C. Hartmann, M. ASCE, G. O. Hoglund, and M. A. Miller in 1944.

Permanent bolts used in structures designed in accordance with these specifications shall be of the aluminum alloy known commercially as 24S-T4. Such bolts have a specified minimum ultimate shear strength of 37 kips per sq in.

TABLE 1.—Alloys to Be Used for Rivets

Designation before driving	Driving procedure	Designation after driving	Typical shear strength[a]
A17S-T4........	Cold, as received	A17S-T3	33
61S-T4........	Hot, 990° F to 1,050° F	61S-T43	24

[a] Typical ultimate shear strength of the driven rivet, in kips per square inch.

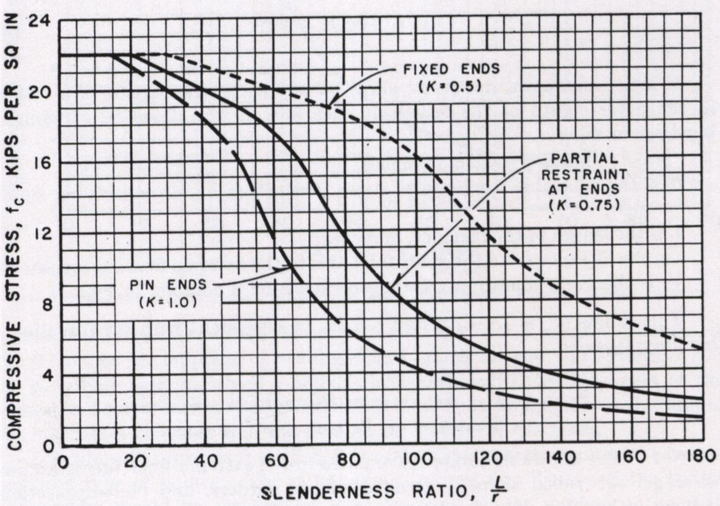


Fig. 2.—Allowable Compressive Stresses for Axially Loaded Columns (Gross Section)

The materials covered by these specifications are heat treated for maximum strength. They cannot be welded without a considerable loss in strength. Structures designed under these specifications shall be assembled by riveting or bolting.

[2] "Joining Aluminum Alloys," by E. C. Hartmann, G. O. Hoglund, and M. A. Miller, *Steel*, August 7, 1944, p. 84.

PART II. SPECIFICATIONS

Section A. Summary of Allowable Stresses

The allowable stresses to be used in proportioning the parts of a structure shall be as follows:

Specification	Description	Stress in kips per square inch
A-1	Axial tension, net section (see Specification H-4)......	22
A-2	Tension in extreme fibers of shapes, girders, and built-up members subject to bending, net section (see Specification H-4)........................	22
A-3	Axial compression (see Section B)....................	....
A-4	Compression in extreme fibers of shapes, girders, and built-up members subject to bending (see Section C)	....
A-5	Compression in plates, legs, and webs (see Section D)	....
A-6	Stress in extreme fibers of pins.....................	34
A-7	Shear in plates and webs (see Section E).............	....
A-8	Shear in aluminum alloy A17S-T3 rivets, cold driven (see Tables 4 and 5)............................	10
A-9	Shear in aluminum alloy 61S-T43 rivets, driven at temperatures of from 990° F to 1,050° F (see Tables 4 and 6)..	8
A-10	Shear in turned bolts of aluminum alloy 24S-T4 in reamed holes (see Table 4).........................	12
A-11	Shear in pins......................................	16
A-12	Bearing on pins....................................	30
A-13	Bearing on hot-driven or cold-driven rivets, milled stiffeners, turned bolts in reamed holes, and other parts in fixed contact (see Section G)..................	36

Section B. Column Design

B-1. Allowable Compressive Stress in Columns.—The allowable compressive stress on the gross section of axially loaded columns shall be determined from the curves in Fig. 2. Let k be a factor describing end restraint. Ordinarily the curve for partial restraint ($k = 0.75$) shall be used. The curves for pin-ended and fixed-ended columns, also shown in Fig. 2, may be used as a guide in the selection of allowable compressive stresses for those cases in which the degree of end restraint is known to be different from that represented by $k = 0.75$. It is important, however, that no allowable stresses higher than those given for the case of $k = 0.75$ be used in actual design unless a detailed analysis of the structure demonstrates convincingly that a value of k smaller than 0.75 is justified for the member in question.

Columns having cross sections involving webs and outstanding legs of such proportions that local buckling may control the design shall be checked by the method outlined in Section D.

B-2. Maximum Slenderness Ratio.—The ratio of unsupported length to least radius of gyration for compression members shall not exceed 120.

B–3. Connections.—Compression members shall be so designed that the main elements of the section will be connected directly to the gusset plates, pins, or other members.

B–4. Compression Splices.—Members designed for compression, if faced for bearing, shall be spliced on four sides sufficiently to hold the abutting parts true to place. The splice shall be as near a panel point as practicable and shall be designed to transmit at least one half of the stress through the splice material. Members not faced for bearing shall be fully spliced for the computed stress. In either case, adequate provision shall be made for transmitting shear.

B–5. Stay Plates.—On the open sides of compression members, the flanges shall be connected by lacing bars, and there shall be stay plates as near each end as practicable. There shall be stay plates at intermediate points where the lacing is interrupted. In main members the length of the end stay plates shall not be less than one and one-fourth times the distance between rivet lines. The thickness of stay plates shall not be less than one fortieth of the distance between rivet lines.

B–6. Diagonal Lacing.—The slenderness ratio of the part of the flange between the lacing bar connections shall be not more than two thirds of the slenderness ratio of the member.

The angle between the center line of the lacing bar and the center line of the column shall be about 60° for single lacing and about 45° for double lacing.

B–7. Combined Compression and Bending.—The allowable bending stress in a member which carries bending moment in addition to uniform compression (as, for example, an eccentrically loaded column) shall be determined from one of the following two formulas—whichever gives the lower value:

a. Failure by Bending in Plane of Bending Forces.—The maximum bending stress (compression) which may be permitted at or near the center of the unsupported length, in addition to uniform compression, P/A, equals

$$f_b = \left(f_1 - \frac{P}{A}\right)\left(1 - \frac{P/A}{f_{C_p}}\right) \qquad (1)$$

in which (in kips per square inch):

P/A is the average compressive stress on the gross cross section (A) of a member, produced by a column load, P;

f_1 is the compressive stress taken from Figs. 4, 5 or 6 for the compression flange of a member when considered as a beam; and

f_{C_p} is the allowable compressive working stress for a member considered as an axially loaded column tending to fail in the plane of the bending forces.

b. Failure by Buckling Normal to Plane of Bending Forces.—The maximum bending stress (compression) which may be permitted at or near the center of the unsupported length, in addition to the uniform compression, P/A, equals

$$f_b = f_B\left(1 - \frac{P/A}{f_{C_n}}\right)\left(1 - \frac{P/A}{f_{CE}}\right) \qquad (2)$$

in which (in kips per square inch):

f_B is the allowable compressive working stress for a member considered as a beam; f_{C_n} is the allowable working stress for a member considered as an axially loaded column tending to fail in a direction normal to the plane of bending forces; and

$$f_{CE} = \frac{74{,}000}{\left(\frac{L}{r}\right)^2}$$

In the equation for f_{CE}, $\frac{L}{r}$ is the slenderness ratio for a member considered as a column tending to fail in the plane of the bending forces.

B–8. Transverse Shear in Columns.—In designing lacing or shear webs for columns, the maximum shear on the column shall be computed from the formula:

$$V = P\,\frac{4.5\,r^2\,(f_B - P/A)}{f_C\,L\,c} + V_t \qquad (3a)$$

but shall not be taken less than

$$V = 0.02\,P + V_t \qquad (3b)$$

in which:

V is the maximum transverse shear on any transverse section of a column in the outer eighth of the length at each end, in the direction of assumed bending, in kips;

r is the radius of gyration, in inches;

f_C is the allowable compressive stress taken from Fig. 2, in kips per square inch;

L is the length of the member, in inches;

c is the distance from the centroidal axis to the extreme fiber, in inches; and

V_t is the shear due to any transverse loads on a column, in kips.

The values of f_B, f_C, L, r, and c must be consistent with the direction of bending assumed.

Section C. Allowable Compressive Stresses in Flanges of Beams and Girders

C–1.—The allowable compressive stress in the extreme fiber (gross section) of single-web rolled shapes, extruded shapes, girders, and built-up sections, subject to bending, shall be determined from the curve in Fig. 3. The terms used in Fig. 3 are defined as follows:

L is the laterally unsupported length of compression flange (clear distance between supports at which the beam is prevented from lateral displacement), in inches;

S_c is the section modulus for the beam about the axis normal to the web (compression side), in inches;

$$B = I_1\,d\,\sqrt{11.7 + \frac{J}{I_1}\left(\frac{L}{d}\right)^2};$$

I_1 is the moment of inertia for the beam about the axis parallel to the web, in inches to the fourth power;
J is the torsion factor, in inches[4]; and
d is the depth of beam, in inches.

In the case of beams having top and bottom flanges of different lateral stiffness, I_1 should be calculated as if both flanges were the same as the compression flange. Values of the torsion factor J are published for many standard shapes.[3]

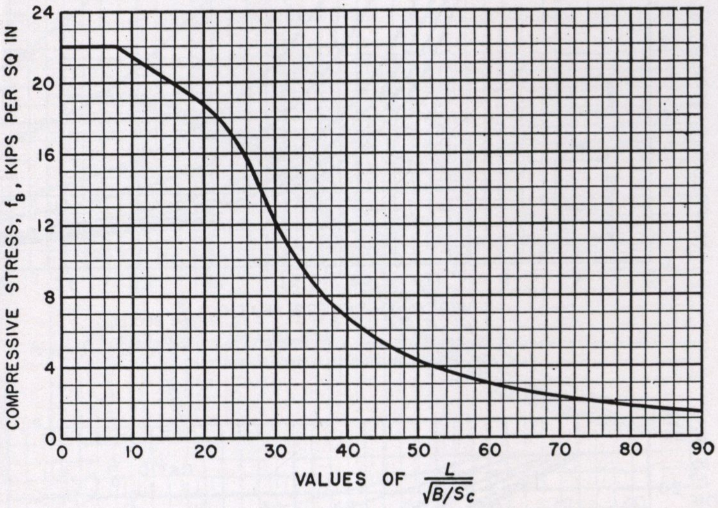


FIG. 3.—ALLOWABLE COMPRESSIVE STRESSES IN BEAM AND GIRDER FLANGES (GROSS SECTION)

Values of J for plates and shapes not published may be calculated by assuming the section to be composed of rectangles and taking the sum of the terms $b\,t^3/3$ for each rectangle, in which b equals the length and t, the thickness of the rectangle, both in inches. The value of J for a built-up member is the sum of the individual values of J of the sections of which it is composed.

The allowable stresses from Fig. 3 provide a safe margin against the lateral buckling type of failure. The outstanding compression flanges of the beams and girders should be checked for local buckling by the method outlined in Section D.

Table 2 lists values of allowable stress determined from Fig. 3 and Section D for various laterally unsupported lengths of a number of standard I-beams and H-beams. Table 3 lists similar values for standard channels.

Because of their tube-like cross section, double-web box girders are very stiff in torsion compared with single-web girders of comparable size, and hence, lateral buckling failures such as are considered in Fig. 3 do not occur in such girders. For double-web box girders it is necessary only to check for local buckling of the flanges by the method outlined in Section D.

[3] "Alcoa Structural Handbook," Aluminum Co. of America, Pittsburgh, Pa., 1950, pp. 87–112.

SECTION D. ALLOWABLE COMPRESSIVE STRESS FOR PLATES, LEGS, AND WEBS

D–1.—For struts consisting of a single angle or a T-section, the compressive stress on the gross area shall not exceed the values given by the curves in Fig. 4 or Fig. 2, whichever is smaller.

TABLE 2.—ALLOWABLE COMPRESSIVE STRESS IN BEAM FLANGES FOR VARIOUS VALUES OF LATERALLY UNSUPPORTED LENGTH OF COMPRESSION FLANGE, *L*, IN INCHES

Procedure.—Maximum allowable bending moments are found by multiplying the allowable compressive stresses (in kips per square inch) by the gross section modulus of the beam. The stress on the net section of the tension flange must also be kept within allowable limits.

Depth (in.)	Weight (lb per ft)	Section modulus (in.³)	VALUES OF L									
			16	32	64	96	128	160	192	256	352	480
(a) I-BEAMS												
2	0.804	0.481	20.6[a]	18.8	10.2	6.1	4.4	3.5	2.9	2.1	1.6	....
2	1.473	0.782	21.6	19.9	17.0	12.2	9.1	7.2	6.0	4.5	3.3	2.4
2.5	1.850	1.162	21.8	20.3	18.3	15.6	12.0	9.6	8.0	6.0	4.4	3.2
3	2.02	1.68	21.4	19.8	15.8	10.2	7.5	5.9	5.0	3.7	2.7	2.0
3	2.67	1.95	21.7	20.3	17.9	14.1	10.4	8.3	6.9	5.2	3.8	2.8
4	2.72	3.03	21.7	20.0	15.7	9.7	7.1	5.5	4.6	3.4	2.5	1.8
4	3.74	3.59	21.8[a]	20.4	17.8	13.6	10.0	7.9	6.5	4.9	3.5	2.6
5	3.53	4.90	21.8[a]	20.2	16.2	9.9	7.1	5.5	4.5	3.4	2.4	1.8
5	5.25	6.09	21.9[a]	20.6	18.2	14.7	10.8	8.5	7.0	5.2	3.8	2.8
6	4.43	7.36	21.8[a]	20.5	16.9	10.5	7.3	5.6	4.6	3.4	2.4	1.8
6	6.13	8.77	21.8[a]	20.7	18.0	13.6	9.8	7.6	6.3	4.6	3.4	2.5
7	5.42	10.48	21.8[a]	20.8	17.5	11.2	7.7	5.9	4.7	3.4	2.5	1.8
7	7.12	12.12	21.8[a]	20.9	18.2	13.4	9.4	7.3	5.9	4.4	3.1	2.3
8	6.53	14.39	21.8[a]	21.0	18.0	12.2	8.2	6.1	5.0	3.6	2.5	1.8
8	9.07	17.18	21.8[a]	21.1	18.7	15.0	10.5	8.0	6.6	4.8	3.4	2.5
9	7.72	19.09	21.8[a]	21.2	18.5	13.2	8.8	6.5	5.2	3.7	2.6	1.9
9	10.68	22.75	21.8[a]	21.2	18.9	15.6	10.9	8.3	6.7	4.9	3.5	2.5
10	9.01	24.68	21.8[a]	21.3	18.8	14.5	9.4	6.9	5.5	3.9	2.7	2.0
10	12.45	29.41	21.8[a]	21.4	19.2	16.3	11.5	8.7	7.0	5.1	3.6	2.6
12	11.31	36.35	21.8[a]	21.5	19.1	15.2	9.8	7.1	5.6	3.9	2.7	1.9
12	17.78	50.81	22.0	21.7	19.8	17.6	14.0	10.4	8.4	6.0	4.2	3.1
(b) H-BEAMS												
4	4.85	5.36	21.7[a]	21.4[a]	19.6	17.7	15.1	11.8	9.7	7.2	5.2	3.8
5	6.63	9.53	21.5[a]	21.5[a]	20.1	18.5	16.4	13.1	10.6	7.7	5.5	4.0
6	8.04	14.69	21.3[a]	21.3[a]	20.5	19.0	17.2	14.4	11.4	8.0	5.6	4.0
6	9.40	15.81	21.3[a]	21.3[a]	20.6	19.2	17.7	15.6	12.7	9.0	6.3	4.6
8	11.51	28.23	20.7[a]	20.7[a]	20.4[a]	19.7[a]	18.6	16.7	13.7	9.1	6.0	4.2
8	13.32	30.23	20.7[a]	20.7[a]	20.4[a]	19.8[a]	18.8	17.2	14.8	10.0	6.7	4.7

[a] These values are governed by local buckling (see Section D). All other values are determined from Fig. 3, Section C.

D–2.—For compression members other than those consisting of a single angle or a T-section, the following procedure shall be followed to provide a suitable margin of safety against the weakening effects of local buckling of flat plates, legs, and webs:

a.—Compute the compressive stress f_c on the flat plate, leg, or web in question, based on the design loads and the gross area, without regard to local

buckling. This stress must be within allowable limits as defined in Sections B and C.

b.—Find the limiting value of b/t corresponding to the stress, f_c, by the use of Fig. 5 or Fig. 6. If the flat plate, leg, or web has a ratio of unsupported width to thickness not exceeding this limiting value, local buckling is not a problem and the full gross area of the plate, leg, or web may be considered effective.

TABLE 3.—ALLOWABLE COMPRESSIVE STRESS IN CHANNEL FLANGES FOR VARIOUS VALUES OF LATERALLY UNSUPPORTED LENGTH OF COMPRESSION FLANGE, L, IN INCHES

Procedure.—Maximum allowable bending moments are found by multiplying the allowable compressive stresses (in kips per square inch) by the gross section modulus of the beam. The stress on the net section of the tension flange must also be kept within allowable limits.

Depth (in.)	Weight (lb per ft)	Section modulus (in.^{3})	VALUES OF L									
			16	32	64	96	128	160	192	256	352	480
3	1.46	1.10	21.2	19.3	13.2	8.4	6.2	4.9	4.1	3.1	2.2	1.6
3	2.13	1.38	21.6	20.0	17.4	13.2	9.9	7.8	6.5	4.8	3.5	2.6
4	1.90	1.92	21.4	19.2	12.3	7.6	5.5	4.4	3.6	2.7	2.0	1.4
4	2.58	2.29	21.6[a]	19.7	15.7	10.2	7.4	5.9	4.9	3.6	2.6	2.0
5	2.38	3.00	21.6[a]	19.4	12.3	7.4	5.3	4.2	3.4	2.8	1.8	1.3
5	4.09	4.17	21.7[a]	20.2	17.4	12.9	9.5	7.5	6.2	4.6	3.4	2.5
6	2.91	4.37	21.5[a]	19.7	12.9	7.4	5.2	4.1	3.3	2.4	1.8	1.3
6	4.63	5.80	21.7[a]	20.2	16.7	11.1	8.0	6.3	5.2	3.9	2.8	2.0
7	3.47	6.08	21.6[a]	20.0	14.0	7.8	5.4	4.1	3.4	2.5	1.8	1.3
7	6.13	8.64	21.7[a]	20.4	17.5	12.5	9.0	7.0	5.8	4.3	3.1	2.2
8	4.38	8.46	21.7[a]	20.2	15.3	8.4	5.7	4.3	3.5	2.6	1.8	1.3
8	6.99	11.34	21.7[a]	20.5	17.5	12.2	8.7	6.7	5.5	4.1	2.9	2.1
9	4.74	10.60	21.6[a]	20.4	16.0	8.8	5.8	4.4	3.5	2.5	1.8	1.3
9	8.90	15.75	21.7[a]	20.8	18.1	13.7	9.7	7.4	6.2	4.5	3.2	2.4
10	5.43	13.47	21.6[a]	20.6	16.6	9.3	6.1	4.5	3.6	2.5	1.8	1.3
10	10.67	20.69	21.7[a]	21.0	18.5	14.8	10.4	8.0	6.5	4.8	3.4	2.5
12	7.63	21.97	21.6[a]	21.0	17.9	11.3	7.2	5.2	4.1	2.9	2.0	1.4
12	12.45	29.94	21.7[a]	21.1	18.6	14.6	9.9	7.5	6.0	4.4	3.1	2.2

[a] These values are governed by local buckling (see Section D). All other values are determined from Fig. 3, Section C.

c.—If the flat plate, leg, or web has a ratio of unsupported width to thickness greater than the limiting $\frac{b}{t}$-ratio found in step b, only a part of its unsupported width shall be included in computing its effective area. The part of the unsupported width of any individual flat plate, leg, or web which may be considered effective shall be found as follows:

$$b_e = b\frac{f_1}{f_c} \qquad (4)$$

in which:

b_e is that part of the unsupported width considered effective, in inches;

b is the unsupported width, in inches;

f_c is the compressive stress based on gross area from step (a), in kips per square inch; and

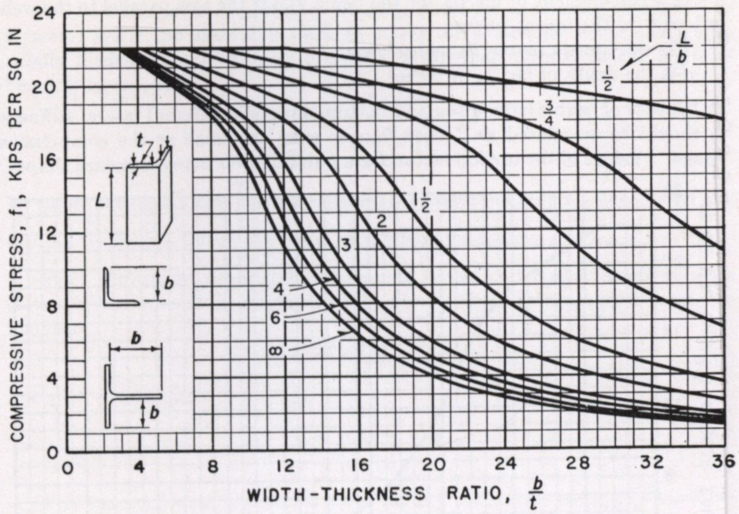


FIG. 4.—ALLOWABLE COMPRESSIVE STRESSES IN OUTSTANDING LEGS OF SINGLE-ANGLE AND T-SECTION STRUTS (GROSS SECTION)

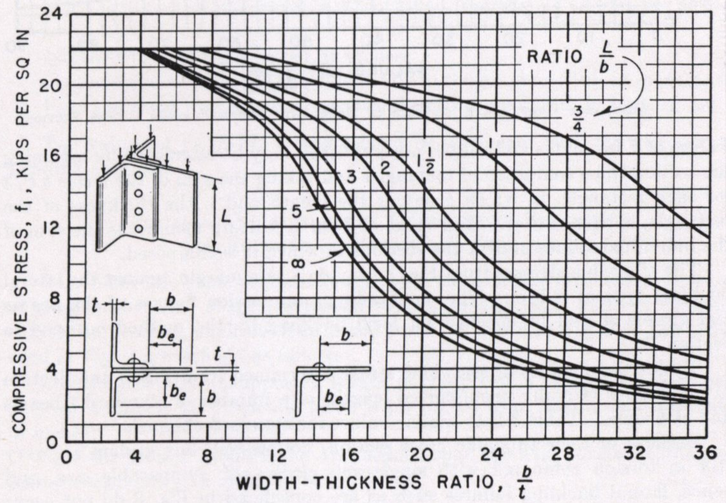


FIG. 5.—CHART FOR DETERMINING EFFECTIVE WIDTH FOR OUTSTANDING LEGS OF ANGLES BUILT INTO OTHER PARTS AND FOR PLATES BUILT IN ALONG ONE EDGE

f_1 is the stress found from Fig. 5 or Fig. 6 corresponding to the $\frac{b}{t}$-value for the plate, leg, or web in question, in kips per square inch.

d.—Compute the compressive stress on the effective area. In the case of an axially loaded column this is simply the axial load divided by the total effective area, which, in turn, is simply the sum of the effective areas of the component parts. In the case of a beam or girder the compressive stress on the effective area shall be determined as follows: Compute the compressive extreme fiber stress f_c for the gross section of the beam or girder and then multiply

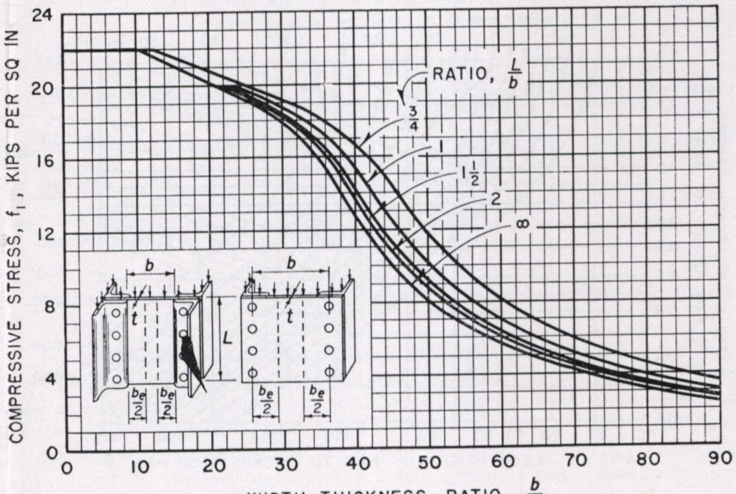


Fig. 6.—Chart for Determining Effective Width for Flat Plates Built In Along Two Edges

this value by the ratio of the gross compression flange area to the effective compression flange area, including in both flange areas not only the flange proper but also that part of the web in the outermost one sixth of the over-all depth of the beam or girder.

e.—The compressive stress on the effective area computed in accordance with step d shall not exceed allowable limits as defined in Sections B and C for the gross area.

f.—Step c provides a suitable factor of safety against the collapse of the member as a whole but does not necessarily provide complete protection against the local buckling of individual flat surfaces at the design load. Where local buckling at the design load cannot be tolerated because of appearance, or for other reasons, the compressive stress on the gross section of the member shall be less than 1.5 times the value given in Fig. 5 or Fig. 6 for the $\frac{b}{t}$-ratio in question.

Section E. Allowable Shear Stresses in Plates and Webs

E-1.—The allowable shear stress on flat webs shall not exceed the values given by the curves in Fig. 7. The values in Fig. 7 apply to the gross area of the web, but the shear on the net area shall not exceed 15 kips per sq in.

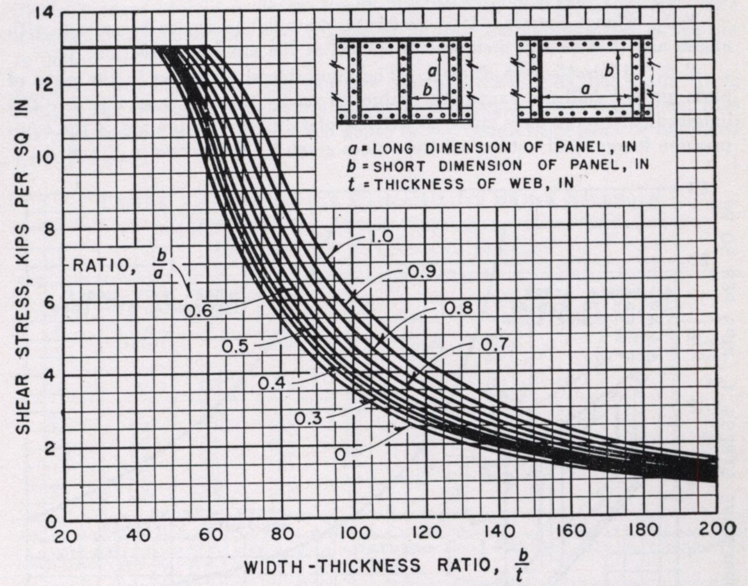


Fig. 7.—Allowable Shear Stresses on Webs; Partial Restraint Assumed at Edges of Rectangular Panels (Gross Section)

Section F. Plate Girder Design

F-1. Proportioning Plate Girders.—Plate girders shall be proportioned by the moment of inertia method, with the gross section used to determine the moment of inertia.

The stress on the net area of the tension flange shall be found by multiplying the stress on the gross section by the ratio of the gross area of the tension flange to the net area. In determining this ratio the tension flange shall be considered to consist of the flange angles and cover plates plus that part of the web included in the outermost one sixth of the over-all height of the girder.

F-2. Allowable Flange Stress.—The allowable compressive stress in the extreme fiber of plate girders shall be determined as outlined in Sections C and D. The numerical value of the term $\sqrt{B/S_c}$, used in Fig. 3, is rarely less than one half of the width, in inches, of the compression flange for a plate girder. This fact is useful in preliminary design.

F-3. Flange Cover Plates.—Cover plates shall extend far enough to allow at least two extra rivets at each end of the plate beyond the theoretical

end, and the spacing of the rivets in the remainder of the plate shall be such as to develop the required strength of the plate at any section.

F-4. Flange Rivets.—The flanges of plate girders shall be connected to the web with enough rivets to transmit the longitudinal shear at any point together with any load that is applied directly on the flange.

F-5. Flange Splices.—It is preferable that flange angles be spliced with angles and that no two members be spliced at the same cross section.

F-6. Allowable Web Stresses.—The allowable shear stress in the webs of plate girders shall not exceed the values given by the curves in Fig. 7. The longitudinal compressive stress in webs of plate girders at the toe of the compression flange shall not exceed the values given by the curves in Fig. 8.

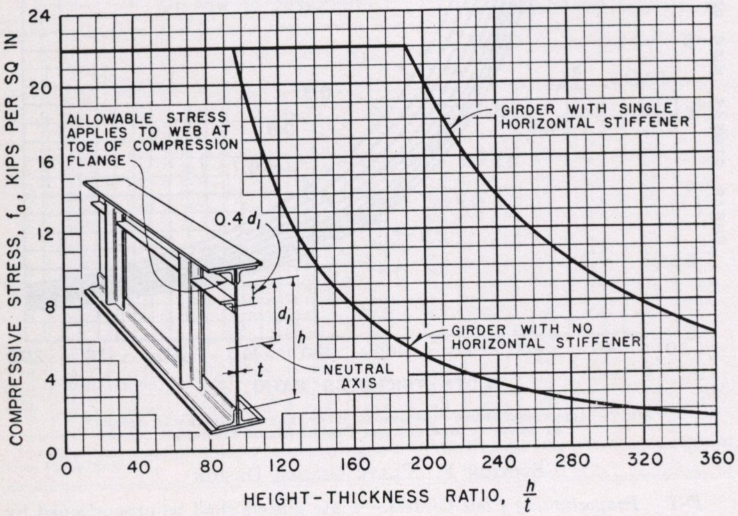


Fig. 8.—Allowable Longitudinal Compressive Stresses for Webs of Girders

F-7. Web Splices.—It is preferable that splices in the webs of plate girders be made with splice plates on both sides of the web.

F-8. Spacing of Vertical Stiffeners to Resist Shear Buckling.—The distance, s, between vertical stiffeners shall not exceed the values given by the solid curves in Fig. 9, which are replots of the curves in Fig. 7. The maximum value of the ratio of stiffener spacing to height of web, s/h, in Fig. 9 shall be determined from the ratio of clear height to thickness, h/t, and the computed shear stress on the girder web. Where a stiffener is composed of a pair of members, one on each side of the web, the distance s shall be the clear distance between the stiffeners. Where a stiffener is composed of a member on one side of the web only, the distance s shall be the distance between rivet lines. In determining the spacing of vertical stiffeners to resist shear buckling in panels

containing a horizontal stiffener located as shown in Fig. 8, the distance h in Fig. 9 may be taken as 90% of the clear height between flanges.

F-9. Size of Vertical Stiffeners to Resist Shear Buckling.—Stiffeners applied to plate girder webs to resist shear buckling shall have a moment of inertia not less than the values given by the dotted curves in Fig. 9. The minimum value of the ratio of the stiffener moment of inertia to the fourth power of the web thickness, I_s/t^4, in Fig. 9, shall be determined from the ratio of height of web to thickness of web, h/t, and the computed shear stress on the girder web.

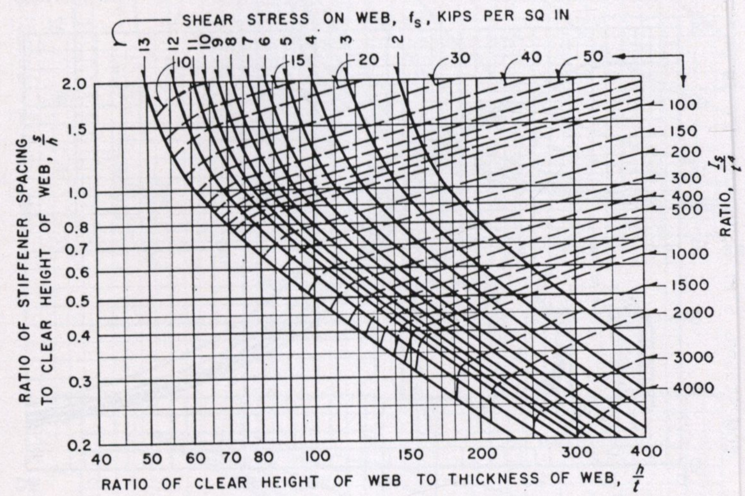


Fig. 9.—Spacing and Moment of Inertia of Vertical Stiffeners to Resist Shear Buckling on Webs of Plate Girders

For a stiffener composed of members of equal size on both sides of the web, the moment of inertia shall be taken about the center line of the web. For a stiffener composed of a member on one side only, the moment of inertia shall be taken about the face of the web in contact with the stiffener. In determining moment of inertia of stiffeners, the term h shall always be taken as the full clear height between flanges, regardless of whether or not a horizontal stiffener is present.

F-10. Vertical Stiffeners at Points of Bearing.—Stiffeners shall be placed in pairs at end bearings of plate girders and at points of bearing of concentrated loads. They shall be connected to the web by enough rivets to transmit the load. Such stiffeners shall have a close bearing against the loaded flanges. Only that part of the stiffener cross section which lies outside the fillet of the flange angle shall be considered effective in bearing.

The moment of inertia of the stiffener shall not be less than that given by the formula:

$$I = I_s + \frac{P\,h^2}{74{,}000} \quad \cdots\cdots (5)$$

in which:

I_s is the moment of inertia, in inches to the fourth power, required to resist shear buckling (Fig. 9);

P is a local load concentration on the stiffener, in kips; and

h is the clear height of the web between flanges, in inches.

F-11. Horizontal Stiffeners.—A horizontal stiffener of the type shown in Fig. 8 shall have a moment of inertia not less than that given by the following formula:

$$I_h = f\,t\,h^3 \left[\left(16 + 90\frac{A_h}{h\,t}\right)\left(\frac{s}{h}\right)^2 + 6\right] \times 10^{-7} \quad \ldots\ldots\ldots\ldots (6)$$

in which:

I_h is the moment of inertia of the horizontal stiffener, in inches to the fourth power;

f is the compressive stress at the toe of the flange angles, in kips per square inch;

t is the thickness of the web, in inches;

h is the clear height of the web between flanges, in inches;

s is the distance between vertical stiffeners, in inches;

and

A_h is the gross area of cross section of the horizontal stiffener, in square inches.

For a stiffener composed of members of equal size on both sides of the web, the moment of inertia shall be taken about the center line of the web. In the case of a stiffener consisting of a member on one side only, the moment of inertia shall be taken about the face of the web in contact with the stiffener.

Eq. 6 must be solved by trial, since both the moment of inertia, I_h, and the area, A_h, of the stiffener are unknown. It is generally convenient to assume as a first approximation that the ratio $\frac{A_h}{h\,t}$ has the value of 0.1.

Section G. Riveted and Bolted Connections

G-1. Allowable Loads.—The allowable loads on rivets and bolts shall be calculated using the allowable shear and bearing stresses listed in Section A with the following exceptions:

a.—If a rivet or a bolt is used in relatively thin plates or shapes the allowable shear stress shall be reduced in accordance with the information given in Table 4.

b.—If the distance from the center of a rivet or bolt to the edge of a plate or shape toward which the pressure of the rivet or bolt is directed is less than twice the diameter of the rivet or bolt, the allowable bearing stress shall be reduced in accordance with the following:

Ratio of edge distance to rivet or bolt diameter	Allowable bearing stress, in kips per square inch
2 or more	36
$1\frac{3}{4}$	33
$1\frac{1}{2}$	30

The allowable loads calculated for cold-driven A17S–T3 rivets are given in Table 5 and those for 61S–T43, hot-driven rivets, are given in Table 6.

G-2. Effective Diameter.—The effective diameter of rivets shall be taken as the hole diameter but shall not exceed the values of hole diameter given in Table 5 for cold-driven rivets and in Table 6 for hot-driven rivets. The effective diameter of pins and bolts shall be the nominal diameter of the pin or bolt.

G-3. Bearing Area.—The effective bearing area of pins, bolts, and rivets shall be the effective diameter multiplied by the length in bearing; except that for countersunk rivets, half of the depth of the countersink shall be deducted from the length.

TABLE 4.—Percentage Reduction in Shear Strength of Aluminum Alloy Rivets Resulting from Their Use in Thin Plates and Shapes[2]

Ratio,[a] D/t	Loss in double shear[b]	Ratio,[a] D/t	Loss in double shear[b]	Ratio,[a] D/t	Loss in: Single shear	Loss in: Double shear	Ratio,[a] D/t	Loss in: Single shear	Loss in: Double shear
(1)	(3)	(1)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
1.5	0	2.2	9.1	2.9	0	18.2	3.5	2.0	26.0
1.6	1.3	2.3	10.4	3.0	0	19.5	3.6	2.4	27.3
1.7	2.6	2.4	11.7	3.1	0.4	20.8	3.7	2.8	28.6
1.8	3.9	2.5	13.0	3.2	0.8	22.1	3.8	3.2	29.9
1.9	5.2	2.6	14.3	3.3	1.2	23.4	3.9	3.6	31.2
2.0	6.5	2.7	15.6	3.4	1.6	24.7	4.0	4.0	32.5
2.1	7.8	2.8	16.9	....	....	....	....	....	....

[a] Ratio of the rivet diameter, D, to the plate thickness, t. The thickness used is that of the thinnest plate in a single shear joint or of the middle plate in a double shear joint. [b] The percentage loss of strength in single shear is zero for D/t less than 3.0.

G-4. Arrangement and Strength of Connections.—Connections shall be arranged to minimize the eccentricity of loading on the member. Members and connections shall be proportioned to take into account any eccentricity of loading introduced by the connections.

G-5. Net Section.—The net section of a riveted tension member is the sum of the net sections of its component parts. The net section of a part is the product of the thickness of the part multiplied by its least net width. The net width for a chain of holes extending across the part in any straight or broken line shall be obtained by deducting from the gross width the sum of the diameters of all the holes in the chain and adding $\frac{s^2}{4\,g}$ for each gage space in the chain. In the correction quantity $\frac{s^2}{4\,g}$:

s is the spacing parallel to direction of load (pitch) of any two successive holes in the chain, in inches; and

g is the spacing perpendicular to direction of load (gage) of the same holes, in inches.

TABLE 5.—ALLOWABLE DESIGN LOAD, IN KIPS PER RIVET, FOR COLD-DRIVEN A17S–T3 RIVETS IN 14S–T6 STRUCTURES
(SHEAR, 10 KIPS PER SQ IN. AND BEARING, 36 KIPS PER SQ IN.[a])

Dimensions, in Inches:																	Dimensions, in Inches:
Rivet diameter	3/8		7/16		1/2		9/16		5/8		3/4		7/8		1		Rivet diameter
Hole diameter	0.386		0.453		0.516		0.578		0.641		0.766		0.891		1.016		Hole diameter
Drill size	W		29/64		33/64		37/64		41/64		49/64		57/64		1 1/64		Drill size
	RIVET IN SINGLE SHEAR (ss) OR IN DOUBLE SHEAR (ds)																
Thickness of plate, or shape, in inches:	ss	ds	ss	ds	ss	ds	ss	ds	ss	ds	ss	ds	ss	ds	ss	ds	Thickness of plate, or shape, in inches:
1/8	1.17	1.74[b]	1.58[c]	2.04[b]	2.01[c]	2.32[b]	2.52[c]	2.60[b]	2.88[b]	2.88[b]	....	....	....	....	....	....	1/8
3/16	1.17	2.19[c]	1.61	2.88[c]	2.09	3.48[b]	2.62	3.90[b]	3.18[c]	4.33[b]	4.42[c]	5.17[b]	5.82[c]	6.02[b]	....	....	3/16
1/4	1.17	2.34	1.61	3.12[c]	2.09	3.91[c]	2.62	4.74[c]	3.23	5.62[c]	4.61	6.89[b]	6.11[c]	8.02[b]	7.78[c]	9.14[b]	1/4
5/16	1.17	2.34	1.61	3.22	2.09	4.13[c]	2.62	5.04[c]	3.23	6.03[c]	4.61	8.14[c]	6.24	10.02[b]	8.04[c]	11.43[b]	5/16
3/8	1.17	2.34	1.61	3.22	2.09	4.18	2.62	5.25	3.23	6.31[c]	4.61	8.62[c]	6.24	11.12[c]	8.11	13.72[b]	3/8
7/16	....	....	1.61	3.22	2.09	4.18	2.62	5.25	3.23	6.45	4.61	8.97[c]	6.24	11.66[c]	8.11	14.58[c]	7/16
1/2	....	....	....	....	2.09	4.18	2.62	5.25	3.23	6.45	4.61	9.22	6.24	12.07[c]	8.11	15.16[c]	1/2
9/16	....	....	....	....	....	....	2.62	5.25	3.23	6.45	4.61	9.22	6.24	12.39[c]	8.11	15.64[c]	9/16
5/8	....	....	....	....	....	....	....	....	3.23	6.45	4.61	9.22	6.24	12.47	8.11	16.00[c]	5/8
3/4	....	....	....	....	....	....	....	....	....	....	4.61	9.22	6.24	12.47	8.11	16.22	3/4
7/8	....	....	....	....	....	....	....	....	....	....	....	....	6.24	12.47	8.11	16.22	7/8
1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	8.11	16.22	1

[a] Assuming distance from center of rivet to edge of member toward which the pressure of the rivet is directed is not less than twice the nominal rivet diameter (see Specification G-1, exception *b*). [b] These values are governed by bearing. [c] These values are governed by reduced shear strengths as indicated in Table 4. All other values are governed by basic allowable shear stress.

TABLE 6.—ALLOWABLE DESIGN LOADS, IN KIPS PER RIVET, FOR HOT-DRIVEN 61S–T43 RIVETS IN 14S–T6 STRUCTURES
(RIVETS DRIVEN AT 990° F TO 1,050° F; SHEAR, 8 KIPS PER SQ IN.; AND BEARING, 36 KIPS PER SQ IN.[a])

Dimensions, in Inches:																	Dimensions, in Inches:
Rivet diameter	3/8		7/16		1/2		9/16		5/8		3/4		7/8		1		Rivet diameter
Hole diameter	0.397		0.469		0.531		0.594		0.656		0.781		0.922		1.063		Hole diameter
Drill size	X		15/32		17/32		19/32		21/32		25/32		59/64		1 1/16		Drill size
	RIVET IN SINGLE SHEAR (ss) OR IN DOUBLE SHEAR (ds)																
Thickness of plate, or shape, in inches:	ss	ds	ss	ds	ss	ds	ss	ds	ss	ds	ss	ds	ss	ds	ss	ds	Thickness of plate, or shape, in inches:
1/8	0.99	1.60[b]	1.35[b]	2.05[b]	1.70[b]	2.39[c]	2.08[b]	2.67[c]	2.49[b]	2.95[c]	....	....	....	....	....	....	1/8
3/16	0.99	1.85[b]	1.38	2.47[b]	1.77	3.01[b]	2.22	3.57[b]	2.66[b]	4.12[b]	3.68[b]	5.17[b]	4.98[b]	6.22[c]	....	....	3/16
1/4	0.99	1.98	1.38	2.68[b]	1.77	3.31[b]	2.22	4.00[b]	2.70	4.71[b]	3.83	6.17[b]	5.23[b]	7.91[b]	6.82[b]	9.59[b]	1/4
5/16	0.99	1.98	1.38	2.76	1.77	3.50[b]	2.22	4.26[b]	2.70	5.06[b]	3.83	6.77[b]	5.34	8.88[b]	7.04[b]	10.88[b]	5/16
3/8	0.99	1.98	1.38	2.76	1.77	3.54	2.22	4.43	2.70	5.29[b]	3.83	7.17[b]	5.34	9.53[b]	7.10	12.04[b]	3/8
7/16	....	....	1.38	2.76	1.77	3.54	2.22	4.43	2.70	5.41	3.83	7.46[b]	5.34	9.99[b]	7.10	12.77[b]	7/16
1/2	....	....	....	....	1.77	3.54	2.22	4.43	2.70	5.41	3.83	7.67	5.34	10.34[b]	7.10	13.28[b]	1/2
9/16	....	....	....	....	....	....	2.22	4.43	2.70	5.41	3.83	7.67	5.34	10.61[b]	7.10	13.69[b]	9/16
5/8	....	....	....	....	....	....	....	....	2.70	5.41	3.83	7.67	5.34	10.68	7.10	14.02[b]	5/8
3/4	....	....	....	....	....	....	....	....	....	....	3.83	7.67	5.34	10.68	7.10	14.20	3/4
7/8	....	....	....	....	....	....	....	....	....	....	....	....	5.34	10.68	7.10	14.20	7/8
1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	7.10	14.20	1

[a] Assuming distance from center of rivet to edge of member toward which the pressure of the rivet is directed is not less than twice the nominal rivet diameter (see Specification G-1, exception *b*). [b] These values are governed by reduced shear strengths as indicated in Table 4. [c] These values are governed by bearing. All other values are governed by basic allowable shear stress.

The net section of the part is obtained from that chain which gives the least net width. The hole diameter to be deducted shall be the actual hole diameter for drilled or reamed holes.

For angles, the gross width shall be the sum of the widths of the legs less the thickness. The gage for holes in opposite legs shall be the sum of the gages from the back of the angle, less the thickness.

For splice members, the thickness shall be only that part of the thickness of the member that has been developed by rivets beyond the section considered.

G–6. Effective Sections of Angles.—If an angle in tension is connected on one side of a gusset plate, the effective section shall be the net section of the connected leg plus one half of the section of the outstanding leg, unless the outstanding leg is connected by a lug angle. In the latter case the effective section shall be the entire net section of the angle, and there shall be at least two extra rivets in the lug angle beyond the gusset plate.

G–7. Grip of Rivets.—If the grip of rivets carrying calculated stress exceeds four and one-half times the diameter the allowable load per rivet shall be

reduced. The reduced allowable load shall be the normal allowable load divided by $\left(\frac{1}{2} + \frac{G}{9\,D}\right)$, in which G is the grip and D the nominal diameter of the rivet. If the grip exceeds six times the diameter, special care shall be taken in driving the rivets to insure that the holes will be filled completely.

G–8. Pitch of Rivets in Built-Up Compression Members.—The pitch in the direction of stress shall be such that the allowable stress on the individual outside plates and shapes, treated as columns having a length equal to the rivet pitch in accordance with Fig. 2, exceeds the calculated stress. In no case, however, shall the pitch in the direction of stress exceed six times the diameter of the rivets; and for a distance of one and one-half times the width of the member at each end, the pitch in the direction of stress shall not exceed three and one-half times the diameter of the rivets.

G–9. Stitch Rivets.—Where two or more web plates are in contact, there shall be stitch rivets to make them act in unison. In compression members, the pitch of such rivets in the direction of stress shall be determined as outlined in Specification G–8. The gage at right angles to the direction of stress shall not exceed twenty times the thickness of the outside plates. In tension members the maximum pitch or gage of such rivets shall be twenty times the thickness of the outside plates; and in tension members composed of two angles in contact, the pitch of the stitch rivets shall not exceed 10 in.

G–10. Minimum Spacing of Rivets.—The distance between centers of rivets shall not be less than three times the diameter of the rivets.

G–11. Edge Distance of Rivets.—The distance from the center of a rivet to a sheared, sawed, rolled, or planed edge shall be not less than one and one-half times the diameter, except in flanges of beams and channels, where the minimum distance may be one and one-fourth times the diameter. For rivets under computed stress, the distance from the center of the rivet to the edge of the plate or shape toward which the pressure of the rivet is directed should normally be at least twice the nominal diameter of the rivet. In cases where a shorter edge distance must be used, the allowable bearing stress shall be reduced in accordance with Specification G–1, exception b.

The distance from the edge of a plate to the nearest rivet line shall not exceed six times the thickness of the plate.

G–12. Sizes of Rivets in Angles.—The diameter of the rivets in angles whose size is determined by calculated stress shall not exceed one fourth of the width of the leg in which they are driven. In angles whose size is not so determined, 1-in. rivets may be used in $3\frac{1}{2}$-in. legs; 7/8-in. rivets, in 3-in. legs; and 3/4-in. rivets, in $2\frac{1}{2}$-in. legs.

G–13. Extra Rivets.—If splice plates are not in direct contact with the parts which they connect, there shall be rivets on each side of the joint in excess of the number required in the case of direct contact, to the extent of two extra lines for each intervening plate.

If rivets carrying calculated stress pass through fillers, the fillers shall be extended beyond the connected member and the extension secured by enough additional rivets to distribute the total stress in the member uniformly over the combined section of the member and filler.

Section H. Miscellaneous Design Rules

H–1. Reversal of Load.—Members subject to reversal of load under the passage of live load shall be proportioned as follows: Determine the tensile load and the compressive load and increase each by 50% of the smaller; then proportion the member and its connections so that the allowable stresses given in Sections A to G, inclusive, will not be exceeded by either increased load.

H–2. Slenderness Ratio of Tension Members.—The ratio of unsupported length to least radius of gyration for tension members shall not exceed the value given by the following formula:

$$\frac{L}{r} = 150 + 10\,f_t \qquad (7)$$

in which f_t is the lowest net section tensile stress to which the member will be subjected in actual service, in kips per square inch.

H–3. Stay Plates for Tension Members.—Segments of tension members not directly connected to each other shall be stayed together. The length of the stay plate shall be not less than three fourths of the distance between rivet lines of the segments. Stay plates shall be connected to each segment of the tension member by at least three rivets. The distance between stay plates shall be such that the slenderness ratio of the individual segments does not exceed that given by Eq. 7, Specification H–2.

H–4. Fatigue.—Tests indicate that riveted members designed in accordance with the requirements of these specifications and constructed so as to be free from severe reentrant corners and other unusual stress raisers will safely withstand at least 100,000 repetitions of maximum live load without fatigue failure regardless of the ratio of minimum to maximum load. Where a greater number of repetitions of some particular loading cycle is expected during the life of the structure, the calculated net section tensile stresses for the loading in question shall not exceed the values given by the curves in Fig. 10. When using the curves in Fig. 10 the reversal-of-load rule in Specification H–1 should be ignored. The final member and connections selected, however, shall be strong enough to satisfy the requirements of Specification H–1.

In considering fatigue action on structures it is well to bear in mind the following points:

a.—The most severe combination of loadings for which a structure is designed (dead load, maximum live load, maximum impact, maximum wind, etc.) rarely occurs in actual service and is of little or no interest from the standpoint of fatigue.

b.—The loading of most interest from the fatigue standpoint is the steady dead load with a superimposed and repeatedly applied live load having an intensity consistent with day-to-day normal operating conditions.

c.—The number of cycles of load encountered in structures is usually small compared with those encountered in fatigue problems involving machine parts. It takes many years of service to accumulate even 100,000 cycles of any significant stress application in most structures as is indicated by the following examples: 100,000 cycles represent 10 cycles every day for 27 years; 10,000,000

cycles represent 20 cycles every hour for 57 years. Care must be taken not to overestimate grossly the number of cycles for any given load condition.

d.—Careful attention to details in design and fabrication pays big dividends in fatigue life. When a fatigue failure occurs in a structure it is usually at a point of stress concentration where the state of stress could have been improved with little or no added expense.

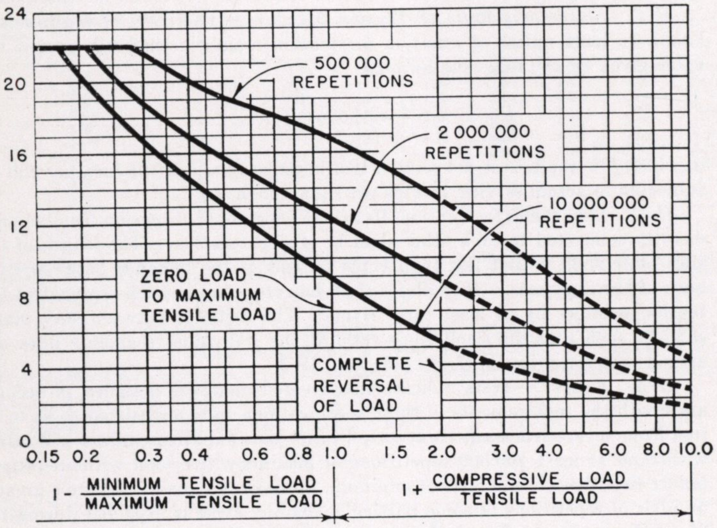


Fig. 10.—Allowable Tensile Stresses on Net Section for Various Numbers of Repetitions of Load Application

Section I. Fabrication

I–1. Laying Out.—

a.—Hole centers may be center-punched and cutoff lines may be punched or scribed. Center-punching and scribing shall not be used where such marks would remain on fabricated material.

b.—A temperature correction shall be applied where necessary in the layout of critical dimensions. The coefficient of expansion shall be taken as 0.000012 per degree Fahrenheit.

I–2. Cutting.—

a.—Material 1/2 in. thick or less may be sheared, sawed, or cut with a router. Material more than 1/2 in. thick shall be sawed or routed.

b.—Cut edges shall be true and smooth, and free from excessive burrs or ragged breaks.

c.—Edges of plates carrying calculated stresses shall be planed to a depth of 1/4 in. except in the case of sawed or routed edges of a quality equivalent to a planed edge.

d.—Reentrant cuts shall be avoided wherever possible. If used they shall be filleted by drilling prior to cutting.

e.—Flame cutting of aluminum alloys is not permitted.

I–3. Heating.—Structural material shall not be heated, with the following exceptions:

a.—Material may be heated to a temperature not exceeding 400° F for a period not exceeding 15 min to facilitate bending. Such heating shall be done only when proper temperature controls and supervision are provided to insure that the limitations on temperature and time are carefully observed.

b.—Hot-driven rivets shall be heated as specified in Section I–5.

I–4. Punching, Drilling, and Reaming.—Rules for punching, drilling, and reaming are as follows:

a.—Rivet or bolt holes in main members shall be subpunched or subdrilled and reamed to finished size after the parts are firmly bolted together. The amount by which the diameter of a subpunched hole is smaller than that of the finished hole shall be at least one-quarter the thickness of the piece and in no case less than 1/32 in. If the metal thickness is greater than the diameter of the hole, punching shall not be used.

b.—Rivet or bolt holes in secondary material not carrying calculated stress may be punched or drilled to finished size before assembly.

c.—The finished diameter of holes for cold-driven rivets shall be not more than 4% greater than the nominal diameter of the rivet.

d.—The finished diameter of holes for hot-driven rivets shall be not more than 7% greater than the nominal diameter of the rivet.

e.—The finished diameter of holes for unfinished bolts shall be not more than 1/16 in. larger than the nominal bolt diameter.

f.—Holes for turned bolts shall be drilled or reamed to give a driving fit.

g.—All holes shall be cylindrical and perpendicular to the principal surface. Holes shall not be drifted in such a manner as to distort the metal. All chips lodged between contacting surfaces shall be removed before assembly.

I–5. Riveting.—

a.—The driven head of aluminum alloy rivets preferably shall be of the flat or the cone-point type, with dimensions as follows:

(1) Flat heads shall have a diameter not less than 1.4 times the nominal rivet diameter and a height not less than 0.4 times the nominal rivet diameter.

(2) Cone-point heads shall have a diameter not less than 1.4 times the nominal rivet diameter and a height, to the apex of the cone, not less than 0.65 times the nominal rivet diameter. The included angle at the apex of the cone shall be approximately 127°.

b.—Rivets shall be driven hot or cold as called for on the plans, provision for heating being as follows:

(1) Hot-driven rivets shall be heated in a hot air type furnace providing uniform temperatures throughout the rivet chamber and equipped with automatic temperature controls.

(2) Hot-driven rivets shall be held at from 990° F to 1,050° F for not less than 15 min and for not more than 1 hour before driving.

(3) Hot rivets shall be transferred from the furnace to the work and driven with a minimum loss of time.

c.—Rivets shall fill the holes completely. Rivet heads shall be concentric with the rivet holes and shall be in proper contact with the surface of the metal.

d.—Defective rivets shall be removed by drilling.

I-6. Welding.—Welding is not permitted.

I-7. Cleaning and Treatment of Metal Surfaces.—

a.—Surfaces of metal shall be cleaned immediately before painting by a method which will remove all dirt, oil, grease, chips, and other foreign substances.

b.—Either of the two following methods of cleaning may be used on exposed metal surfaces:

(1) Chemical Cleaning.—Parts may be immersed in, or swabbed with, a solution of phosphoric acid and organic solvents diluted with water in the ratio of 1:3. The solution temperature shall be between 50° F and 90° F. The solution shall remain in contact with the metal not less than 5 min. Residual solution shall be removed with clear water.

(2) Sandblasting.—Standard mild sandblasting methods may be used on sections more than 1/8 in. thick.

c.—For contacting surfaces only, the metal may be cleaned in accordance with Specification I-7b, or with a solvent such as mineral spirits or benzine.

d.—Flame cleaning is not permitted.

I-8. Painting.—Specifications to control painting operations are as follows:

a.—Metal parts shall be painted as described in Specifications I-8b to I-8h except where the plans specifically permit a deviation.

b.—Contacting metal surfaces shall be painted before assembly with one coat of zinc chromate primer in accordance with United States Navy Department Specification 52P18 or the equivalent, or with one coat of suitable aluminum pigmented calking compound (brushing consistency with chromate pigment added). Zinc chromate paint shall be allowed to dry before assembly of the parts.

c.—In all cases where aluminum work is to be fastened to steel members or other dissimilar metal parts, the aluminum shall be kept from direct contact with such parts by painting the aluminum surface as described in Specification I-8b and by painting the dissimilar metal with a suitable metal priming paint.

d.—Aluminum surfaces to be placed in contact with concrete or masonry construction shall, before installation, be given a heavy coat of an alkali-resistant bituminous paint. The quality of the bituminous paint used shall

be equal to that called for in the Army-Navy Aeronautical Specification AN-P-31. The paint shall be applied as it is received from the manufacturer without the addition of any thinner.

e.—All other surfaces shall be given one shop coat of zinc chromate primer made in accordance with Navy Department Specification 52P18, or one giving equivalent performance.

f.—All surfaces, except those covered by Specifications I-8b, I-8c, and I-8d, shall be given a second shop coat of paint consisting of 2 lb of aluminum paste pigment (ASTM Specification D962-48T, Type II, Class A) per gallon of varnish meeting Federal Specification TTV81a, Type II, or the equivalent. Sufficient Prussian blue shall be added to permit detection of an incomplete application of the subsequent paint coat.

g.—After erection, bare spots shall be touched up with zinc chromate primer followed by a touch-up coat of aluminum paint as specified in Specifications I-8e and I-8f.

h.—The completed structure shall be finished according to one of the following methods:

(1) One field coat of aluminum paint as specified in Specification I-8f, except that Prussian blue shall be omitted from the field coat.

(2) One or more field coats of alkyd base enamel pigmented to meet a desired color scheme.

PART III. EXPLANATION OF SPECIFICATIONS

Section A. Summary of Allowable Stresses

A-1. Basic Tensile Design Stress.—The basic tensile design stress of 22 kips per sq in. represents a factor of safety of 2.41 based on the specified tensile yield strength. This is a larger factor of safety with respect to yield strength than is ordinarily encountered in specifications for structural steel. In selecting this rather large factor of safety on yield strength, the committee was influenced to a considerable extent by the fact that there is a smaller spread between yield strength and tensile strength in this aluminum alloy than is commonly encountered in structural steels.

A-8, A-9, and A-13. Allowable Stresses on Rivets.—The allowable shearing and bearing stresses on rivets were selected on the basis of the results of numerous shearing and bearing tests. The factors of safety used are greater than those used for most of the other allowable stresses.[2]

A-6, A-11, and A-12. Allowable Stresses on Pins.—The allowable bending, shearing, and bearing stresses on pins were selected to have about the same relation to the corresponding properties of the material as is the case in standard steel specifications. It is not anticipated that any wide use of pins will be made in aluminum alloy structures but it is assumed that where they are used they will be of the same material as the structural members themselves, and that they would probably be obtained in the form of rolled rod, ASTM Specification B211-49T(CS41A-T6).

Section B. Column Design

B–1. Curves for Allowable Compressive Stresses in Axially Loaded Columns.—The curves in Fig. 2 are the tangent-modulus column curves with a factor of safety of 2.5 and with a cutoff at the basic allowable design stress of 22 kips per sq in. The formulas for all three curves can be written[4,5]

$$fc = \frac{\pi^2 E_t}{2.5\left(\frac{kL}{r}\right)^2} \quad \text{(8)}$$

in which:

fc is the allowable compressive stress on the gross cross-sectional area, in kips per square inch;

E_t is the tangent modulus taken from Fig. 1 at stress corresponding to $2.5(fc)$, in kips per square inch;

L is the length of the column, in inches;

r is the least radius of gyration of the column, in inches; and

k is a factor describing the end conditions as defined in Fig. 2.

For values of slenderness ratio, L/r, greater than 72, the formula for the partial restraint curve in Fig. 2 reduces to

$$fc = \frac{74{,}000}{\left(\frac{L}{r}\right)^2} \quad \text{(9)}$$

B–7. Formulas for Combined Compression and Bending.—Eq. 1, which applies to bending in the direction of the applied bending moment, takes into account the additional bending moment due to the deflection of the column.[6]

Eq. 2, covering failure by buckling normal to the plane of the bending forces, is a simplified design formula which is conservative compared to test results and to the theoretical solution for this case.[7] A modification of this solution has been suggested by H. N. Hill, Assoc. M. ASCE, and J. W. Clark, Jun. ASCE.[8]

B–8. Formula for Transverse Shear on Columns.—Eq. 3a is based on the transverse component of the column load at the point of maximum slope of the column in its deflected position. A derivation by Mr. Hartmann has been published elsewhere.[6]

---

[4] "Column Strength of Various Aluminum Alloys," by R. L. Templin, R. G. Sturm, E. C. Hartmann, and M. Holt, *Aluminum Research Laboratories Technical Paper No. 1*, Aluminum Co. of America, Pittsburgh, Pa., 1938.

[5] "Inelastic Column Theory," by F. R. Shanley, *Journal of the Aeronautical Sciences*, Vol. 14, 1947, pp. 261–268.

[6] Discussion by E. C. Hartmann of "Rational Design of Steel Columns," by D. H. Young, *Transactions*, ASCE, Vol. 101, 1936, pp. 475–481.

[7] "Torsional and Flexural Buckling of Bars of Thin-Walled Open Section Under Compressive and Bending Loads," by J. N. Goodier, *Transactions*, A.S.M.E., Vol. 64, 1942, pp. A-103–A-107.

[8] "Lateral Buckling of Eccentrically Loaded I- and H-Section Columns," by H. N. Hill and J. W. Clark. *Proceedings*, First U. S. National Congress of Applied Mechanics (publication pending).

Section C. Curve for Allowable Compressive Stress in Beam and Girder Flanges

C–1.—The curve in Fig. 3 is based on the theoretical solution for the critical bending moment in I-beams as given by S. Timoshenko.[9] It represents a factor of safety of 2.5 applied to the theoretical solution for beams subjected to a uniform bending moment. It is assumed that at the ends of the laterally unsupported length there is partial restraint against rotation about a vertical axis and complete restraint against lateral displacement or rotation about a horizontal axis parallel to the web. The part of the curve for values of $\frac{L}{\sqrt{B/S_c}}$ greater than 27.5 is based on elastic action, whereas the remainder is simply an extension of the same formula using tangent modulus rather than initial modulus. The curve has a cutoff at the basic allowable design stress of 22 kips per sq in. It is important to note that the term L is defined as "laterally unsupported length of compression flange," which is not necessarily the same as the span of the beam or the girder. The case of uniform bending moment has been used in setting up Fig. 3 because it is a good approximation of conditions frequently encountered in actual design, and because it is somewhat more conservative than many of the other cases that might have been selected.

For values of $\frac{L}{\sqrt{B/S_c}}$ greater than 27.5, the curve in Fig. 3 may be represented by the formula:

$$f_B = \frac{10{,}900}{\left(\frac{L}{\sqrt{B/S_c}}\right)^2} \quad \text{(10)}$$

The curve in Fig. 3 is based on a theoretical solution applicable only to I-beams having cross sections symmetrical about both axes. The modified interpretation of the term I_1 indicated in specification C–1, however, permits the curve to be used without serious error for beams and girders having one flange differing in lateral stiffness from the other. It should be used with caution in cases of beams and girders which are unsymmetrical by a considerable margin. (In connection with this subject several supplementary references [7,10,11,12,13] will be of interest.)

Section D. Curves for Design of Flat Plates, Legs and Webs

The curves of Figs. 4, 5, and 6 are based on values of critical stress compiled by Mr. Hill in 1940.[14] Partial restraint along the supported edges and loaded

---

[9] "Theory of Elastic Stability," by S. Timoshenko, McGraw-Hill Book Co., Inc., New York, N. Y., 1936.

[10] "The Lateral Instability of Unsymmetrical I-Beams," by H. N. Hill, *Journal of the Aeronautical Sciences*, Vol. 9, 1942, pp. 175–180.

[11] "The Lateral Stability of Equal-Flanged Aluminum-Alloy I-Beams Subjected to Pure Bending," by C. Dumont and H. N. Hill, *Technical Note No. 770*, National Advisory Committee for Aeronautics, Washington, D. C., 1940.

[12] "Lateral Stability of Unsymmetrical I-Beams and Trusses in Bending," by George Winter, *Transactions*, ASCE, Vol. 108, 1943, pp. 247–268.

[13] "Strength of Beams as Determined by Lateral Buckling," by Karl de Vries, *ibid.*, Vol. 112, 1947, pp. 1245–1320.

[14] "Chart for Critical Compressive Stress of Flat Rectangular Plates," by H. N. Hill, *Technical Note No. 773*, National Advisory Committee for Aeronautics, Washington, D. C., 1940.

edges was assumed in all cases except for the supported edge in Fig. 4, which was considered simply supported. Parts of the curves that represent critical buckling stresses above the elastic range are computed by using the tangent modulus instead of the modulus of elasticity, a procedure which is known to be conservative when applied to problems of plate buckling.[15] A factor of safety of 2.5 against critical buckling has been used in all three charts and in all cases the curves have a cutoff at the basic allowable design stress of 22 kips per sq in.

When a flat plate, leg, or web is built in along one or both edges to other parts of a compression member which offer partial edge restraint, the local buckling of the plate, leg, or web does not precipitate collapse of the member as a whole as it probably would in the case of a single-angle strut. For this reason it is proper to permit a decreased factor of safety against local buckling in such cases if suitable precautions are taken to avoid collapse. Step c of Specification D–2 provides a simple method for accomplishing this result by introducing the well-known "effective width" concept. After a plate, leg, or web buckles, a part of its area is considered to be ineffective in supporting load, whereas a strip along each supported edge is considered still fully effective in working with the supporting material to which it is attached. The formula (Eq. 4) for effective width used in step c of Specification D–2 is generally more conservative than other accepted methods of calculating effective width.[16,17,18,19]

Section E. Curves for Allowable Shear Stress in Webs

E–1.—The values of allowable stress in Fig. 7 are obtained by applying a factor of safety of 2 to the critical shear buckling stresses for flat plates with the edges about halfway between the fixed and hinged conditions.[9,20,21]

Those parts of the curves of Fig. 7 which represent critical buckling stresses above the elastic stress range are computed from formulas for elastic buckling with the tangent modulus substituted for the modulus of elasticity. For a given value of critical shear stress, the tangent modulus is that corresponding to an axial stress equal to $\sqrt{3}$ times the shear stress.[22] As in the case of compressive buckling of flat plates, the tangent modulus is conservative.

For values of allowable stress below 10.4 kips per sq in., the curves of Fig. 7 may be represented by the formula:

$$f_v = \frac{35{,}000}{(b/t)^2}\left[1 + 0.75\left(\frac{b}{a}\right)^2\right] \qquad (11)$$

[15] "Buckling Stresses for Flat plates and Sections," by Elbridge Z. Stowell, George J. Heimerl, Charles Libove, and Eugene E. Lundquist, *Proceedings*, ASCE, Separate No. 77, July, 1951.

[16] "The Strength of Thin Plates in Compression," by Theodor von Kármán, Ernest E. Sechler, and L. H. Donnell, *Transactions*, A.S.M.E., Vol. 54, 1932, pp. 53–57.

[17] "The Apparent Width of the Plate in Compression," by Karl Marguerre, *Technical Memorandum No. 833*, National Advisory Committee for Aeronautics, Washington, D. C., 1937.

[18] "Strength of Thin Steel Compression Flanges," by George Winter, *Transactions*, ASCE, Vol. 112, 1947, pp. 527–576.

[19] "Performance of Thin Steel Compression Flanges," by George Winter, preliminary publication, 3d Cong. of the International Assn. for Bridge and Structural Engrs., Liege, Belgium, 1948.

[20] "Formulas for Stress and Strain," by Raymond J. Roark, McGraw-Hill Book Co., Inc., New York, N. Y., 1938.

[21] "Observations on the Behavior of Aluminum Alloy Test Girders," by R. L. Moore, *Transactions*, ASCE, Vol. 112, 1947, pp. 901–920.

[22] "Critical Shear Stress of an Infinitely Long Plate in the Plastic Region," by Elbridge Z. Stowell, *Technical Note No. 1681*, National Advisory Committee for Aeronautics, Washington, D. C., 1948.

Section F. Plate Girder Design

F–6. Curves for Allowable Longitudinal Compressive Stress in Webs of Girders.—The curve in Fig. 8 for girders with no horizontal stiffeners is based on the critical buckling stress for rectangular flat plates under pure bending in the plane of the plate. Partial restraint is assumed at the toes of the flanges (about halfway between the solution given by Mr. Timoshenko for the case of a plate simply supported on all four edges[9] and the solution of K. Nolke for a plate with the loaded edges simply supported and the other two edges fixed).[23]

The curve in Fig. 8 for girders with a single horizontal stiffener is based on the critical buckling stress given by Mr. Timoshenko for plates simply supported on all four edges under combined bending and axial stress in the plane of the plate.[9] The simple support condition is used for this case because the horizontal stiffener would provide comparatively little restraint against rotation. The location of the horizontal stiffener shown in the sketch in Fig. 8 is chosen so that the parts of the plate above and below the stiffener will buckle at approximately the same load.

A factor of safety against buckling of 1.5 was used for the curves of Fig. 8. Although this factor of safety is not as large as some used elsewhere in these specifications, it is considered adequate in this instance since tests have shown that the critical bending stress for girder webs may be considerably exceeded without affecting the load-carrying capacity of the girder.[21,23] Use of Fig. 8, however, will prevent buckling from occurring at design stresses.

The curves of Fig. 8 may be represented by the following formulas: No horizontal stiffener—

$$f_a = \frac{200{,}000}{\left(\frac{h}{t}\right)^2} \qquad (12a)$$

and single horizontal stiffener—

$$f_a = \frac{800{,}000}{\left(\frac{h}{t}\right)^2} \qquad (12b)$$

The curves are cut off at the basic allowable design stress of 22 kips per sq in.

F–8 and F–9. Curves for Spacing and Moment of Inertia of Vertical Stiffeners.—The curves for determining stiffener spacing, in Fig. 9, are merely replots of the data of Fig. 7. The curves of I_s/t^4 in Fig. 9 represent the following formula:

$$I_s = 8 \times 10^{-5} \frac{f_s\, h^3\, t\left(\frac{s}{h}\right)}{1 + 5\left(\frac{s}{h}\right)^3} \qquad (13)$$

in which f_s is the average shear stress on the web in kips per square inch.

Eq. 13 is designed to fit the theoretical solution of M. Stein and R. W. Fralich[24] for values of s/h between 0.2 and 1.0. This solution does not cover

[23] "Buckling of Webs in Deep Steel I-Girders," by Georg Wastlund and Sten G. A. Bergman, rept. of investigation made at the Royal Inst. of Technology, Stockholm, Sweden, 1947.

[24] "Critical Shear Stress of Infinitely Long, Simply Supported Plate with Transverse Stiffeners," by Manuel Stein and Robert W. Fralich, Technical Note No. 1851, National Advisory Committee for Aeronautics, Washington, D. C., 1949.

values of s/h greater than 1.0. In this range, however, Eq. 13 is conservative in comparison with the recommendations of L. S. Moisseiff.[1]

F-10. Formula for Moment of Inertia of Stiffeners at Points of Bearing.—Eq. 5 simply states that the moment of inertia of a stiffener at a point of bearing should be equal to the sum of the moment of inertia required to resist the tendency of the web to buckle and the moment of inertia required for the stiffener to carry the bearing load as a column with length equal to the height of the web.

F-11. Formula for Radius of Gyration of Horizontal Stiffeners.—Eq. 6, for the moment of inertia of horizontal stiffeners, is based on the theoretical work of C. Dubas, reported by F. Bleich.[25]

Section H. Miscellaneous Design Rules

H-2. Formula for Slenderness Ratio of Tension Members.—Eq. 7 is designed to yield slenderness ratios in agreement with values generally accepted for tension members, at the same time taking into account the fact that the higher the minimum tensile stress on the member the less tendency there will be for the member to bend or sway.

H-4. Curves of Allowable Tensile Stress on Net Section for Various Numbers of Repetitions of Load Application.—The curves in Fig. 10 are plotted from the results of fatigue tests conducted at the Aluminum Research Laboratories of the Aluminum Company of America at New Kensington, Pa., on 14S-T6 butt joints with double straps joined with eight cold-driven 5/8-in. A17S-T3 rivets. The type of testing equipment and specimen (Type M1) used are illustrated in a paper by R. L. Templin,[26] M. ASCE, in 1939, and a paper by Mr. Hartmann, J. O. Lyst, and H. J. Andrews,[27] Jun. ASCE, in 1944.

A factor of safety of 1.2 has been applied to the test data and all curves are cut off at the basic allowable design stress of 22 kips per sq in. The right-hand part of the diagram is largely based on extrapolation of the data, but this is not considered to be a serious matter since the design of most members in this range will be governed primarily by Specification H-1 rather than by fatigue considerations.

Respectfully submitted,

F. Baron
J. W. Clark
R. Ebenbach
J. T. Ellis
C. N. Gaylord
I. G. Hedrick, Jr.
S. A. Kilpatrick
R. B. B. Moorman
J. S. Newell
F. L. Plummer
E. J. de Ridder
F. J. Tamanini

E. C. Hartmann, *Chairman*

Committee of the Structural Division on Design in Lightweight Structural Alloys

December 6, 1951

[25] "The Buckling Strength of Metal Structures," by Friedrich Bleich, McGraw-Hill Book Co., Inc., New York, N. Y., 1952, p. 422.

[26] "Fatigue Machines for Testing Structural Units," by R. L. Templin, *Proceedings*, A.S.T.M., Vol. 39, 1939, pp. 711-722.

[27] "Fatigue Tests of Riveted Joints," by E. C. Hartmann, J. O. Lyst, and H. J. Andrews, *Wartime Report W55*, National Advisory Committee for Aeronautics, Washington, D. C., 1944.

SYMBOLS FOR "ELEMENTS OF SECTIONS" TABLES

NOMINAL DIMENSIONS—Symbols used to indicate nominal dimensions of sections are as follows:

A — Area, inches^2.
b — Breadth or Width, inches.
D — Diameter, inches.
d — Depth, inches.
  Gage, inches.
  Grip, inches.
R — Radius, inches.
t — Thickness, inches.
  Weight, pounds per foot.

Note: Actual dimensions may deviate from nominal dimensions by an amount not greater than the commercial tolerance.

ELEMENTS—Symbols used to indicate elements of sections are as follows:

I — Moment of Inertia, inches^4.
r — Radius of Gyration, inches.
  $r = \sqrt{I/A}$, where
  A = area of section, inches^2.
S — Section Modulus, inches^3.
  $S = I/c$, where
  c = perpendicular distance from neutral axis to extreme fiber, inches.
X — Horizontal Neutral Axis: axis of greatest moment of inertia for symmetrical sections.
Y — Vertical Neutral Axis. axis of least moment of inertia for symmetrical sections.
Z — Inclined Neutral Axis: axis of least moment of inertia for unsymmetrical sections.
Θ — Angle of inclination of Axis Z—Z from vertical, degrees.
x — Distance parallel to Axis X—X, inches.
y — Distance parallel to Axis Y—Y, inches.
J — Torsion Factor, inches^4.
  $J = T/G\Theta$, where
  Θ = angle of twist, radians per inch of length;
  T = torque, inch-pounds;
  G = modulus of rigidity, 3,800,000 psi for aluminum alloys.
E — Modulus of Elasticity, 10,300,000 psi for aluminum alloys.

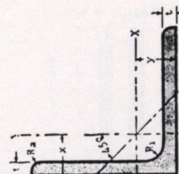
Note: Elements have been computed on the basis of nominal dimensions. Fillets and roundings have been included in all calculations except those for Torsion Factor, J.

WEIGHTS—All weights shown here are based on the density of 14S and 17S aluminum alloys which is .101 pounds per cubic inch. For material of different density, multiply the weight per foot in the table by the applicable conversion factor.

METAL OR ALLOY	DENSITY Lb/Cu In.	WEIGHT CONVERSION FACTOR
3S	.099	.98
61S	.098	.97
Magnesium	.063	.64
Steel	.284	2.9

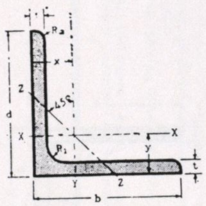
Table 18—EQUAL ANGLES

Size d x b	Thickness t	A	W	R_1	R_2	I_{xy}	S_{xy}	r_{xy}	x_y	I_z	r_z	J
½ x ½	1/16	.059	.071	1/16	1/32	.0013	.0038	.150	.146	.0006	.097	.00008
⅝ x ⅝	3/32	.111	.134	⅛	3/64	.0037	.0084	.183	.187	.0015	.117	.00034
	⅛	.140	.169	1/16	1/16	.0046	.0109	.182	.199	.0020	.120	.00081
¾ x ¾	1/16	.089	.108	⅛	3/32	.0043	.0079	.220	.199	.0018	.142	.00012
	3/32	.132	.159	⅛	3/32	.0063	.0118	.219	.214	.0026	.141	.00041
	⅛	.171	.207	⅛	3/32	.0082	.0157	.219	.227	.0034	.141	.00098
	3/16	.246	.297	⅛	3/32	.0112	.0224	.214	.251	.0049	.141	.0033
1 x 1	1/16	.122	.147	1/16	1/32	.0118	.0162	.311	.271	.0048	.199	.00016
	3/32	.178	.216	⅛	3/32	.0161	.0223	.301	.276	.0066	.193	.00055
	⅛	.234	.283	⅛	3/32	.0208	.0293	.298	.290	.0085	.191	.00130
	3/16	.339	.411	⅛	3/32	.0291	.0424	.293	.314	.0124	.191	.00439
	¼	.437	.529	⅛	3/32	.0361	.0544	.287	.336	.0162	.193	.01042
1⅛ x 1⅛	⅛	.27	.32	3/16	⅛	.030	.037	.33	.32	.012	.21	.0015
1¼ x 1¼	3/32	.23	.28	3/16	⅛	.033	.036	.38	.34	.014	.24	.0007
	⅛	.30	.36	3/16	⅛	.042	.046	.37	.35	.017	.24	.0016
	3/16	.43	.53	3/16	⅛	.059	.068	.37	.37	.025	.24	.0055
	¼	.56	.68	3/16	⅛	.074	.087	.36	.40	.032	.24	.013
	5/16	.68	.83	3/16	⅛	.088	.106	.36	.42	.040	.24	.025
1½ x 1½	3/32	.28	.34	3/16	⅛	.058	.053	.46	.40	.024	.30	.0008
	⅛	.36	.44	3/16	⅛	.074	.068	.45	.41	.031	.29	.0020
	3/16	.53	.64	3/16	⅛	.107	.100	.45	.44	.044	.29	.0066
	¼	.69	.83	3/16	⅛	.135	.130	.44	.46	.057	.29	.016
	5/16	.84	1.02	3/16	⅛	.161	.158	.44	.48	.070	.29	.031
	⅜	.99	1.19	3/16	⅛	.184	.185	.43	.51	.083	.29	.053



For key to symbols, see explanation Page 82.

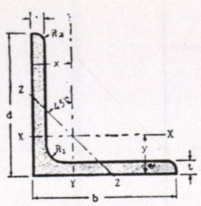
Table 18—EQUAL ANGLES (Continued)



Size d x b	Thickness t	A	W	R_1	R_2	I_{xy}	S_{xy}	r_{xy}	x_y	I_z	r_z	J
1¾ x 1¾	3/32	.32	.39	3/32	3/64	.096	.075	.55	.47	.039	.35	.0010
	1/8	.42	.51	3/16	1/8	.121	.094	.53	.47	.050	.34	.0023
	3/16	.62	.75	3/16	1/8	.174	.139	.53	.50	.072	.34	.0077
	1/4	.81	.98	3/16	1/8	.223	.181	.52	.52	.093	.34	.018
	5/16	1.00	1.21	3/16	1/8	.266	.221	.52	.55	.113	.34	.036
	3/8	1.17	1.42	3/16	1/8	.306	.259	.51	.57	.134	.34	.062
2 x 2	1/8	.49	.59	1/4	1/8	.18	.13	.61	.53	.08	.40	.0026
	3/16	.72	.87	1/4	1/8	.27	.19	.61	.56	.11	.39	.0088
	1/4	.94	1.14	1/4	1/8	.34	.24	.60	.58	.14	.39	.021
	5/16	1.16	1.40	1/4	1/8	.41	.30	.60	.61	.17	.39	.041
	3/8	1.37	1.65	1/4	1/8	.47	.35	.59	.63	.20	.39	.070
	7/16	1.57	1.89	1/4	1/8	.53	.39	.58	.65	.23	.39	.112
2½ x 2½	1/8	.62	.75	1/4	1/8	.37	.20	.77	.65	.15	.50	.0033
	3/16	.91	1.10	1/4	1/8	.54	.30	.77	.68	.22	.49	.011
	1/4	1.19	1.45	1/4	1/8	.69	.39	.76	.71	.29	.49	.026
	5/16	1.47	1.78	1/4	1/8	.84	.48	.76	.73	.35	.49	.051
	3/8	1.74	2.11	1/4	1/8	.98	.56	.75	.76	.41	.48	.088
	7/16	2.00	2.42	1/4	1/8	1.10	.64	.74	.78	.47	.48	.140
	1/2	2.26	2.73	1/4	1/8	1.22	.72	.73	.80	.53	.48	.208
3 x 3	3/16	1.10	1.33	5/16	1/4	.93	.42	.92	.80	.38	.59	.013
	1/4	1.43	1.73	5/16	1/4	1.18	.54	.91	.82	.49	.58	.031
	5/16	1.77	2.14	5/16	1/4	1.45	.67	.91	.85	.60	.58	.061
	3/8	2.10	2.55	5/16	1/4	1.70	.80	.90	.87	.70	.58	.105
	7/16	2.43	2.94	5/16	1/4	1.94	.92	.89	.90	.81	.58	.167
	1/2	2.74	3.32	5/16	1/4	2.16	1.04	.89	.92	.91	.58	.250
	9/16	3.05	3.69	5/16	1/4	2.37	1.15	.88	.94	1.01	.58	.356
	5/8	3.35	4.06	5/16	1/4	2.57	1.26	.88	.97	1.12	.58	.488

For key to symbols, see explanation Page 82

Table 18—EQUAL ANGLES (Concluded)



Size d x b	Thickness t	A	W	R_1	R_2	I_{xy}	S_{xy}	r_{xy}	x_y	I_z	r_z	J
3½ x 3½	1/4	1.69	2.05	3/8	1/4	1.93	.76	1.07	.94	.80	.69	.036
	5/16	2.09	2.53	3/8	1/4	2.37	.94	1.06	.97	.98	.68	.071
	3/8	2.49	3.01	3/8	1/4	2.79	1.11	1.06	1.00	1.15	.68	.123
	7/16	2.87	3.48	3/8	1/4	3.18	1.28	1.05	1.02	1.32	.68	.195
	1/2	3.25	3.94	3/8	1/4	3.56	1.45	1.05	1.05	1.49	.68	.292
	9/16	3.62	4.39	3/8	1/4	3.92	1.61	1.04	1.07	1.65	.67	.415
	5/8	3.99	4.83	3/8	1/4	4.26	1.77	1.03	1.09	1.81	.67	.570
4 x 4	1/4	1.94	2.35	3/8	1/4	2.94	1.00	1.23	1.07	1.21	.79	.042
	5/16	2.41	2.91	3/8	1/4	3.61	1.24	1.23	1.10	1.48	.78	.081
	3/8	2.86	3.46	3/8	1/4	4.26	1.48	1.22	1.12	1.75	.78	.141
	7/16	3.31	4.01	3/8	1/4	4.87	1.71	1.21	1.15	2.01	.78	.223
	1/2	3.75	4.54	3/8	1/4	5.46	1.93	1.21	1.17	2.26	.78	.333
	9/16	4.19	5.07	3/8	1/4	6.02	2.15	1.20	1.20	2.51	.77	.475
	5/8	4.61	5.58	3/8	1/4	6.56	2.36	1.19	1.22	2.76	.77	.651
	11/16	5.03	6.09	3/8	1/4	7.08	2.57	1.19	1.24	3.00	.77	.867
	3/4	5.44	6.58	3/8	1/4	7.57	2.77	1.18	1.26	3.25	.77	1.125
5 x 5	3/8	3.60	4.36	1/2	3/8	8.37	2.30	1.52	1.36	3.44	.98	.176
	7/16	4.18	5.05	1/2	3/8	9.65	2.67	1.52	1.38	3.96	.97	.279
	1/2	4.74	5.74	1/2	3/8	10.89	3.03	1.52	1.41	4.47	.97	.417
	9/16	5.30	6.42	1/2	3/8	12.08	3.39	1.51	1.43	4.97	.97	.593
	5/8	5.85	7.08	1/2	3/8	13.22	3.73	1.50	1.46	5.47	.97	.814
	11/16	6.40	7.74	1/2	3/8	14.33	4.07	1.50	1.48	5.96	.97	1.08
	3/4	6.93	8.39	1/2	3/8	15.39	4.41	1.49	1.51	6.44	.96	1.41
6 x 6	3/8	4.35	5.27	1/2	3/8	14.85	3.38	1.85	1.60	6.07	1.18	.211
	7/16	5.05	6.11	1/2	3/8	17.15	3.93	1.84	1.63	7.01	1.18	.335
	1/2	5.74	6.95	1/2	3/8	19.38	4.46	1.84	1.66	7.92	1.17	.500
	9/16	6.43	7.78	1/2	3/8	21.54	4.99	1.83	1.68	8.82	1.17	.712
	5/8	7.10	8.59	1/2	3/8	23.64	5.51	1.82	1.71	9.70	1.17	.977
	11/16	7.77	9.40	1/2	3/8	25.67	6.02	1.82	1.73	10.57	1.17	1.30
	3/4	8.43	10.20	1/2	3/8	27.64	6.52	1.81	1.76	11.43	1.16	1.69

For key to symbols, see explanation Page 82.

Excerpt: Reynolds Aluminum Structural Design Handbook.

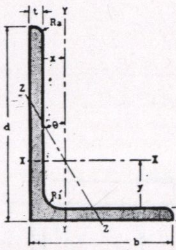


Table 19—UNEQUAL ANGLES

Size d x b	Thickness t	A	W	R_1	R_2	I_x	S_x	r_x	y_x	I_y	S_y	r_y	x_y	θ_z	I_z	r_z	J
¾ x ⅜	3/32	.099	.120	1/8	3/64	.0054	.0114	.232	.279	.0009	.0031	.094	.098	13°44′	.0006	.077	.00031
1 x ⅝	1/8	.187	.226	1/16	1/16	.0181	.0279	.312	.351	.0054	.0117	.170	.165	20°34′	.0033	.132	.00106
	1/4	.345	.418	1/8	1/16	.0306	.0507	.298	.396	.0089	.0215	.161	.210	9°08′	.0084	.156	.00846
1 x ¾	1/8	.202	.245	1/16	1/16	.0194	.0288	.309	.329	.0092	.0169	.214	.205	28°23′	.0051	.158	.00114
1¼ x ¾	3/32	.18	.22	3/32	3/64	.029	.035	.40	.42	.088	.014	.21	.17	19°47′	.005	.16	.0005
1¼ x 1	1/8	.27	.32	1/8	1/16	.040	.047	.39	.39	.023	.031	.29	.27	31°51′	.012	.21	.0015
1½ x ¾	1/8	.27	.32	1/8	1/16	.061	.064	.48	.54	.010	.018	.20	.17	14°25′	.007	.16	.0015
	3/16	.39	.47	1/8	3/32	.085	.091	.47	.57	.014	.025	.19	.19	13°45′	.009	.16	.0049
1½ x ⅞	3/16	.41	.50	1/8	3/32	.090	.093	.47	.54	.022	.034	.23	.23	18°08′	.014	.18	.0052
1½ x 1	5/32	.37	.45	5/32	5/64	.080	.081	.47	.50	.027	.036	.27	.26	23°02′	.015	.20	.0032
	1/4	.56	.68	3/16	1/8	.117	.122	.46	.53	.040	.057	.27	.29	22°23′	.025	.21	.0130
1½ x 1¼	1/8	.33	.40	3/16	1/8	.070	.066	.46	.44	.044	.047	.37	.32	33°59′	.022	.26	.0018
	3/16	.48	.58	3/16	1/8	.100	.097	.46	.47	.063	.069	.36	.35	33°53′	.032	.26	.0060
	1/4	.63	.76	3/16	1/8	.127	.126	.45	.49	.079	.090	.36	.37	33°36′	.041	.26	.0143
1⅝ x 1¼	1/8	.34	.41	1/8	1/8	.087	.077	.51	.50	.045	.048	.36	.31	29°55′	.024	.26	.0019
1¾ x 1⅛	3/16	.51	.61	3/16	3/32	.152	.132	.55	.59	.049	.058	.31	.29	21°47′	.029	.24	.0063
1¾ x 1¼	1/8	.36	.44	3/16	1/8	.108	.090	.55	.54	.046	.048	.36	.30	26°22′	.026	.27	.0020
	3/16	.53	.64	3/16	1/8	.156	.132	.54	.57	.066	.071	.35	.32	26°08′	.037	.26	.0066
	1/4	.69	.83	3/16	1/8	.199	.172	.54	.60	.083	.092	.35	.35	25°47′	.048	.26	.016

For key to symbols, see explanation Page 82.

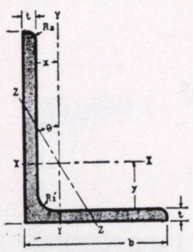


Table 19—UNEQUAL ANGLES (Continued)

Size d x b	Thickness t	A	W	R_1	R_2	I_x	S_x	r_x	y_x	I_y	S_y	r_y	x_y	θ_z	I_z	r_z	J
2 x 1¼	1/8	.39	.47	3/16	1/8	.158	.117	.63	.65	.047	.049	.35	.28	21°05′	.028	.27	.0021
	3/16	.58	.70	3/16	1/8	.228	.172	.63	.68	.068	.072	.34	.31	20°52′	.041	.27	.0071
	1/4	.75	.91	3/16	1/8	.291	.224	.62	.70	.086	.093	.34	.33	20°31′	.053	.26	.017
2 x 1⅜	1/4	.79	.95	1/4	1/8	.302	.228	.62	.68	.114	.113	.38	.37	24°14′	.067	.29	.018
2 x 1½	1/8	.42	.51	3/16	1/8	.17	.12	.63	.60	.08	.07	.44	.36	28°44′	.04	.32	.0023
	3/16	.62	.75	3/16	1/8	.24	.18	.62	.63	.12	.10	.43	.38	28°36′	.06	.32	.0077
	1/4	.81	.98	3/16	1/8	.31	.23	.62	.66	.15	.14	.43	.41	28°20′	.08	.32	.018
	5/16	1.00	1.21	3/16	1/8	.37	.28	.61	.68	.18	.16	.42	.43	28°0′	.10	.32	.036
	3/8	1.17	1.42	3/16	1/8	.43	.33	.60	.70	.20	.19	.41	.45	27°37′	.12	.32	.062
2 x 1¾	1/4	.88	1.07	1/4	1/8	.33	.24	.61	.62	.23	.18	.51	.49	34°44′	.11	.36	.020
2¼ x 1½	1/4	.88	1.07	1/4	1/8	.43	.29	.70	.76	.15	.14	.42	.39	23°09′	.09	.32	.020
2½ x 1¼	1/8	.46	.55	3/16	3/32	.30	.18	.81	.87	.05	.05	.34	.25	14°45′	.03	.27	.0024
	3/16	.68	.82	1/4	3/32	.43	.27	.80	.89	.07	.08	.33	.28	14°29′	.05	.27	.0082
	1/4	.88	1.07	1/4	3/32	.55	.35	.79	.92	.09	.10	.32	.30	14°10′	.06	.26	.020
2½ x 1½	1/8	.49	.59	1/4	1/8	.31	.19	.80	.80	.09	.07	.42	.32	19°40′	.05	.33	.0026
	3/16	.72	.87	1/4	1/8	.46	.27	.79	.84	.12	.11	.41	.35	19°38′	.08	.32	.0088
	1/4	.94	1.14	1/4	1/8	.59	.36	.79	.86	.16	.14	.41	.37	19°25′	.10	.32	.021
	5/16	1.16	1.40	3/16	1/8	.71	.44	.78	.89	.19	.17	.40	.39	19°06′	.12	.32	.041
	3/8	1.37	1.65	1/4	1/8	.82	.51	.77	.91	.22	.20	.40	.42	18°42′	.14	.32	.070
2½ x 2	1/8	.55	.67	1/4	1/8	.34	.19	.79	.72	.20	.13	.60	.48	31°57′	.10	.43	.0029
	3/16	.82	.99	1/4	1/8	.50	.29	.78	.75	.29	.19	.59	.51	31°58′	.15	.42	.010
	1/4	1.07	1.29	1/4	1/8	.65	.38	.78	.78	.37	.25	.58	.53	31°51′	.19	.42	.023
	5/16	1.32	1.59	1/4	1/8	.78	.46	.77	.80	.44	.30	.58	.55	31°41′	.23	.42	.046

For key tp symbols, see explanation Page 82.

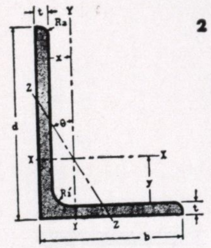


Table 19—UNEQUAL ANGLES (Continued)

Size d x b	Thickness t	A	W	R_1	R_2	I_x	S_x	r_x	y_x	I_y	S_y	r_y	x_y	θ_z	I_z	r_z	J
2 1/2 x 2	3/8	1.55	1.88	1/4	1/8	.91	.54	.76	.83	.51	.36	.57	.58	31°28′	.27	.42	.079
	7/16	1.78	2.16	1/4	1/8	1.02	.62	.76	.85	.57	.41	.57	.60	31°13′	.31	.42	.126
	1/2	2.01	2.43	1/4	1/8	1.13	.69	.75	.87	.63	.46	.56	.62	30°56′	.35	.42	.188
3 x 1 1/2	1/4	1.08	1.30	5/16	1/8	.98	.51	.95	1.08	.16	.14	.39	.34	14°22′	.11	.32	.023
3 x 2	3/16	.91	1.10	5/16	3/16	.82	.40	.95	.94	.29	.19	.56	.46	23°25′	.17	.43	.011
	1/4	1.19	1.44	5/16	3/16	1.06	.52	.94	.97	.38	.25	.56	.48	23°22′	.22	.43	.026
	5/16	1.47	1.78	5/16	3/16	1.29	.65	.94	1.00	.45	.30	.56	.51	23°13′	.27	.43	.051
	3/8	1.74	2.11	5/16	3/16	1.51	.76	.93	1.03	.53	.36	.55	.53	23°0′	.31	.42	.088
	7/16	2.00	2.42	5/16	3/16	1.71	.88	.92	1.05	.59	.41	.55	.56	22°44′	.36	.42	.140
	1/2	2.26	2.73	5/16	3/16	1.90	.99	.92	1.07	.66	.46	.54	.58	22°25′	.40	.42	.208
3 x 2 1/2	1/4	1.31	1.58	5/16	1/4	1.12	.53	.92	.89	.70	.38	.73	.64	34°03′	.35	.52	.029
	5/16	1.62	1.95	5/16	1/4	1.37	.66	.92	.92	.86	.47	.73	.67	34°0′	.43	.51	.056
	3/8	1.92	2.32	5/16	1/4	1.60	.78	.91	.94	1.00	.55	.72	.69	33°54′	.51	.51	.097
	7/16	2.21	2.67	5/16	1/4	1.82	.90	.91	.97	1.14	.64	.72	.72	33°46′	.58	.51	.154
	1/2	2.49	3.02	5/16	1/4	2.03	1.01	.90	.99	1.26	.72	.71	.74	33°37′	.65	.51	.229
3 1/2 x 2 1/2	1/4	1.43	1.73	5/16	1/4	1.73	.72	1.10	1.09	.73	.38	.71	.60	26°23′	.41	.53	.031
	5/16	1.77	2.14	5/16	1/4	2.12	.89	1.09	1.12	.89	.48	.71	.62	26°18′	.50	.53	.061
	3/8	2.10	2.55	5/16	1/4	2.49	1.06	1.09	1.14	1.05	.57	.71	.65	26°10′	.59	.53	.105
	7/16	2.43	2.94	5/16	1/4	2.84	1.22	1.08	1.17	1.19	.65	.70	.67	26°0′	.67	.53	.167
	1/2	2.74	3.32	5/16	1/4	3.17	1.37	1.08	1.19	1.32	.73	.69	.70	25°48′	.76	.53	.250
3 1/2 x 3	1/4	1.57	1.89	3/8	1/4	1.84	.74	1.08	1.01	1.28	.57	.90	.76	36°13′	.63	.63	.034
	5/16	1.94	2.34	3/8	1/4	2.26	.92	1.08	1.04	1.52	.69	.89	.79	35°40′	.74	.62	.066
	3/8	2.30	2.78	3/8	1/4	2.65	1.09	1.07	1.06	1.79	.82	.88	.82	35°37′	.87	.62	.114
	7/16	2.66	3.21	3/8	1/4	3.03	1.26	1.07	1.09	2.04	.94	.88	.84	35°32′	1.00	.61	.181
	1/2	3.00	3.63	3/8	1/4	3.38	1.42	1.06	1.11	2.27	1.06	.87	.86	35°26′	1.13	.61	.271

For key to symbols, see explanation Page 82.

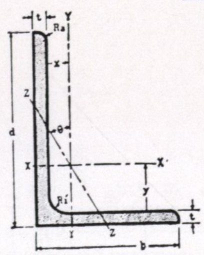


Table 19—UNEQUAL ANGLES (Continued)

Size d x b	Thickness t	A	W	R_1	R_2	I_x	S_x	r_x	y_x	I_y	S_y	r_y	x_y	θ_z	I_z	r_z	J
4 x 3	1/4	1.69	2.05	3/8	1/4	2.68	.96	1.26	1.21	1.29	.56	.87	.72	28°42′	.70	.64	.036
	5/16	2.09	2.53	3/8	1/4	3.29	1.19	1.25	1.24	1.58	.70	.87	.74	28°40′	.85	.64	.071
	3/8	2.49	3.01	3/8	1/4	3.88	1.42	1.25	1.26	1.86	.83	.86	.77	28°35′	1.01	.64	.123
	7/16	2.87	3.48	3/8	1/4	4.43	1.63	1.24	1.29	2.12	.96	.86	.79	28°28′	1.15	.63	.195
	1/2	3.25	3.94	3/8	1/4	4.96	1.85	1.24	1.31	2.36	1.08	.85	.82	28°20′	1.30	.63	.292
	9/16	3.62	4.39	3/8	1/4	5.47	2.05	1.23	1.34	2.60	1.20	.85	.84	28°11′	1.44	.63	.415
	5/8	3.99	4.83	3/8	1/4	5.95	2.25	1.22	1.36	2.82	1.32	.84	.86	28°0′	1.58	.63	.570
4 x 3 1/2	5/16	2.23	2.70	3/8	5/16	3.40	1.19	1.23	1.15	2.42	.93	1.04	.91	36°54′	1.15	.72	.076
	3/8	2.66	3.22	3/8	5/16	4.02	1.43	1.23	1.18	2.85	1.11	1.04	.94	36°53′	1.36	.72	.132
	7/16	3.08	3.72	3/8	5/16	4.61	1.65	1.22	1.21	3.27	1.29	1.03	.96	36°50′	1.57	.71	.209
	1/2	3.49	4.22	3/8	5/16	5.17	1.87	1.22	1.23	3.67	1.46	1.03	.99	36°46′	1.77	.71	.313
5 x 2 1/2	1/2	3.50	4.24	3/8	1/4	8.74	2.77	1.58	1.84	1.46	.77	.64	.60	14°12′	.96	.52	.313
5 x 3	3/8	2.85	3.45	3/8	5/16	7.15	2.15	1.59	1.68	1.93	.84	.82	.69	19°40′	1.17	.64	.141
5 x 3 1/2	5/16	2.56	3.09	7/16	5/16	6.39	1.85	1.58	1.55	2.58	.96	1.00	.81	25°33′	1.45	.75	.086
	3/8	3.05	3.69	7/16	5/16	7.56	2.21	1.58	1.58	3.04	1.15	1.00	.84	25°32′	1.71	.75	.149
	7/16	3.53	4.27	7/16	5/16	8.69	2.56	1.57	1.61	3.49	1.33	.99	.87	25°27′	1.97	.75	.237
	1/2	4.00	4.84	7/16	5/16	9.77	2.90	1.56	1.63	3.91	1.50	.99	.89	25°22′	2.22	.74	.354
	9/16	4.46	5.40	7/16	5/16	10.82	3.24	1.56	1.66	4.32	1.67	.98	.92	25°15′	2.46	.74	.504
	5/8	4.92	5.95	7/16	5/16	11.82	3.56	1.55	1.68	4.70	1.84	.98	.94	25°07′	2.70	.74	.692
6 x 3 1/2	5/16	2.88	3.49	1/2	5/16	10.64	2.64	1.92	1.97	2.70	.98	.97	.74	18°52′	1.65	.76	.097
	3/8	3.43	4.15	1/2	5/16	12.60	3.15	1.92	2.00	3.19	1.17	.96	.77	18°51′	1.95	.75	.167
	7/16	3.98	4.81	1/2	5/16	14.50	3.65	1.91	2.03	3.66	1.35	.96	.80	18°47′	2.24	.75	.265
	1/2	4.51	5.46	1/2	5/16	16.34	4.14	1.90	2.06	4.11	1.53	.95	.82	18°42′	2.52	.75	.396
	9/16	5.04	6.10	1/2	5/16	18.11	4.62	1.90	2.08	4.53	1.71	.95	.85	18°35′	2.80	.75	.564
	5/8	5.56	6.73	1/2	5/16	19.83	5.09	1.89	2.11	4.94	1.88	.94	.87	18°28′	3.07	.74	.773

For key to symbols, see explanation Page 82.

Excerpt: Reynolds Aluminum Structural Design Handbook.

Table 19—UNEQUAL ANGLES (Concluded)

Size d x b	Thickness t	A	W	R_1	R_2	I_x	S_x	r_x	y_x	I_y	S_y	r_y	x_y	θ_z	I_z	r_z	J
6 x 3½	11/16	6.07	7.35	½	5/16	21.49	5.56	1.88	2.13	5.33	2.05	.94	.89	18°20′	3.34	.74	1.03
	¾	6.57	7.95	½	5/16	23.09	6.01	1.87	2.16	5.71	2.21	.93	.92	18°11′	3.61	.74	1.34
6 x 4	⅜	3.60	4.36	½	⅜	13.02	3.17	1.90	1.90	4.63	1.50	1.13	.91	23°33′	2.67	.86	.176
	7/16	4.18	5.05	½	⅜	15.02	3.69	1.90	1.93	5.34	1.74	1.13	.94	23°31′	3.07	.86	.279
	½	4.74	5.74	½	⅜	16.95	4.19	1.89	1.96	6.01	1.98	1.13	.97	23°27′	3.47	.86	.417
	9/16	5.30	6.42	½	⅜	18.82	4.69	1.88	1.98	6.65	2.21	1.12	.99	23°22′	3.86	.85	.593
	⅝	5.85	7.08	½	⅜	20.63	5.17	1.88	2.01	7.27	2.44	1.11	1.02	23°16′	4.24	.85	.814
	11/16	6.40	7.74	½	⅜	22.39	5.64	1.87	2.03	7.86	2.66	1.11	1.04	23°10′	4.61	.85	1.08
	¾	6.93	8.39	½	⅜	24.08	6.11	1.86	2.06	8.43	2.87	1.10	1.07	23°02′	4.98	.85	1.41

For key to symbols, see explanation Page 82.

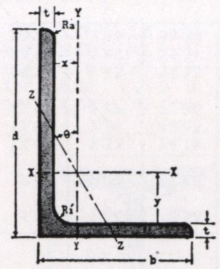


Table 20—STANDARD CHANNELS

Size d	Thickness t	A	W	b	t_1	R_1	R_2	d_1	I_x	S_x	r_x	I_y	S_y	r_y	x_y	Rivet Data: Max D	Rivet Data: Gage	Rivet Data: Grip	J
3	.170	1.21	1.46	1.410	.170	.27	.10	1¾	1.66	1.10	1.17	.20	.20	.40	.44	½	⅞	¼	.031
	.187	1.26	1.52	1.427	.170	.27	.10	1¾	1.69	1.13	1.16	.21	.21	.41	.44	½	⅞	¼	.033
	.258	1.47	1.78	1.498	.170	.27	.10	1¾	1.85	1.24	1.12	.25	.23	.41	.44	½	⅞	¼	.047
	.320	1.66	2.00	1.560	.170	.27	.10	1¾	1.99	1.33	1.10	.28	.25	.41	.45	½	⅞	¼	.066
	.356	1.76	2.13	1.596	.170	.27	.10	1¾	2.07	1.38	1.08	.31	.27	.42	.46	½	⅞	¼	.080
4	.180	1.57	1.90	1.580	.180	.28	.11	2¾	3.83	1.92	1.56	.32	.28	.45	.46	½	1	5/16	.045
	.247	1.84	2.22	1.647	.180	.28	.11	2¾	4.19	2.10	1.51	.37	.31	.45	.45	½	1	5/16	.062
	.320	2.13	2.58	1.720	.180	.28	.11	2¾	4.58	2.29	1.47	.43	.34	.45	.46	½	1	5/16	.090
5	.190	1.97	2.38	1.750	.190	.29	.11	3¾	7.49	3.00	1.95	.48	.38	.49	.48	½	1⅛	5/16	.064
	.225	2.14	2.59	1.785	.190	.29	.11	3¾	7.86	3.14	1.91	.52	.40	.49	.48	½	1⅛	5/16	.074
	.325	2.64	3.20	1.885	.190	.29	.11	3¾	8.90	3.56	1.83	.63	.45	.49	.48	½	1⅛	5/16	.12
	.472	3.38	4.09	2.032	.190	.29	.11	3¾	10.43	4.17	1.76	.81	.53	.49	.51	½	1⅛	5/16	.25
6	.200	2.40	2.91	1.920	.200	.30	.12	4½	13.12	4.37	2.34	.69	.49	.54	.51	⅝	1⅛	5/16	.088
	.225	2.55	3.09	1.945	.200	.30	.12	4½	13.57	4.52	2.31	.73	.51	.54	.51	⅝	1⅛	5/16	.097
	.314	3.09	3.73	2.034	.200	.30	.12	4½	15.18	5.06	2.22	.87	.56	.53	.50	⅝	1⅛	⅜	.14
	.437	3.82	4.63	2.157	.200	.30	.12	4½	17.39	5.80	2.13	1.05	.64	.52	.51	⅝	1⅜	⅜	.26
7	.210	2.87	3.47	2.090	.210	.31	.13	5½	21.27	6.08	2.72	.97	.63	.58	.54	⅝	1¼	⅜	.12
	.230	3.01	3.64	2.110	.210	.31	.13	5½	21.84	6.24	2.69	1.01	.64	.58	.54	⅝	1¼	7/16	.13
	.314	3.60	4.36	2.194	.210	.31	.13	5½	24.24	6.93	2.60	1.17	.70	.57	.52	⅝	1¼	⅜	.18
	.419	4.33	5.24	2.299	.210	.31	.13	5½	27.24	7.78	2.51	1.38	.78	.56	.53	⅝	1¼	7/16	.29
	.524	5.07	6.13	2.404	.210	.31	.13	5½	30.25	8.64	2.44	1.59	.86	.56	.55	⅝	1½	7/16	.47
8	.250	3.62	4.38	2.290	.220	.32	.13	6½	33.85	8.46	3.06	1.40	.81	.62	.56	¾	1⅜	⅜	.17
	.303	4.04	4.89	2.343	.220	.32	.13	6¼	36.11	9.03	2.99	1.53	.85	.61	.55	¾	1⅜	⅜	.21
	.395	4.78	5.78	2.435	.220	.32	.13	6¼	40.04	10.01	2.90	1.75	.93	.61	.55	¾	1½	7/16	.32
	.487	5.51	6.67	2.527	.220	.32	.13	6¼	43.96	10.99	2.82	1.98	1.01	.60	.57	¾	1½	7/16	.47
	.520	5.78	6.99	2.560	.220	.32	.13	6¼	45.37	11.34	2.80	2.07	1.04	.60	.57	¾	1½	7/16	.55

For key to symbols, see explanation Page 82.

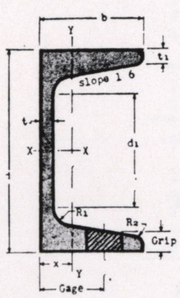


Table 20—STANDARD CHANNELS (Concluded)

Size	Thickness	A	W	b	t_1	R_1	R_2	d_1	I_x	S_x	r_x	I_y	S_y	r_y	x_y	Rivet Data			J
d	t															Max D	Gage	Grip	
9	.230	3.91	4.74	2.430	.230	.33	.14	7¼	47.68	10.60	3.49	1.75	.96	.67	.60	¾	1⅜	7/16	.20
	.285	4.41	5.34	2.485	.230	.33	.14	7¼	51.02	11.34	3.40	1.93	1.01	.66	.59	¾	1⅜	7/16	.24
	.448	5.88	7.11	2.648	.230	.33	.14	7¼	60.92	13.54	3.22	2.42	1.17	.64	.58	¾	1½	½	.47
	.612	7.35	8.90	2.812	.230	.33	.14	7¼	70.89	15.75	3.11	2.94	1.34	.63	.61	¾	1½	½	.92
10	.240	4.49	5.43	2.600	.240	.34	.14	8¼	67.37	13.47	3.87	2.28	1.16	.71	.63	¾	1½	7/16	.25
	.379	5.88	7.11	2.739	.240	.34	.14	8¼	78.95	15.79	3.66	2.81	1.32	.69	.61	¾	1½	7/16	.41
	.526	7.35	8.89	2.886	.240	.34	.14	8¼	91.20	18.24	3.52	3.36	1.48	.68	.62	¾	1¾	½	.75
	.673	8.82	10.67	3.033	.240	.34	.14	8¼	103.45	20.69	3.43	3.95	1.66	.67	.65	¾	1¾	½	1.32
12	.300	6.30	7.63	2.960	.280	.38	.17	10	131.84	21.97	4.57	3.99	1.76	.80	.69	⅞	1¾	½	.46
	.387	7.35	8.89	3.047	.280	.38	.17	10	144.37	24.06	4.43	4.47	1.89	.78	.67	⅞	1¾	½	.61
	.510	8.82	10.67	3.170	.280	.38	.17	10	162.08	27.01	4.29	5.14	2.06	.76	.67	⅞	1¾	½	.95
	.632	10.29	12.45	3.292	.280	.38	.17	10	179.65	29.94	4.18	5.82	2.24	.75	.69	⅞	2	⅝	1.48

For key to symbols, see explanation Page 82.

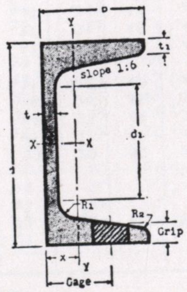
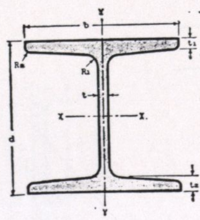
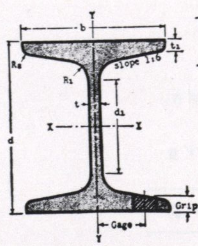


Table 21—H-BEAMS



Size	Thickness	A	W	b	t_1	t_2	R_1	R_2	I_x	S_x	r_x	I_y	S_y	r_y	J
d	t														
4	5/16	4.00	4.85	4.000	.290	.453	.312	.145	10.72	5.36	1.64	3.56	1.78	.94	.22
5	5/16	5.48	6.63	5.000	.330	.503	.312	.165	23.82	9.53	2.08	7.82	3.13	1.19	.34
6	¼	6.64	8.04	5.938	.360	.542	.312	.180	44.06	14.69	2.58	14.18	4.77	1.46	.45
	5/16	7.02	8.49	6.000	.360	.542	.312	.180	45.19	15.06	2.54	14.65	4.88	1.44	.50
	7/16	7.77	9.40	6.125	.360	.542	.312	.180	47.44	15.81	2.47	15.65	5.11	1.42	.62
8	5/16	9.52	11.51	7.938	.358	.560	.312	.179	112.94	28.23	3.45	34.15	8.60	1.89	.68
	⅜	10.01	12.11	8.000	.358	.560	.312	.179	115.58	28.90	3.40	35.01	8.75	1.87	.75
	½	11.01	13.32	8.125	.358	.560	.312	.179	120.92	30.23	3.31	36.79	9.06	1.83	.96

Table 22—STANDARD I-BEAMS



Size	Thickness	A	W	b	t_1	R_1	R_2	d_1	I_x	S_x	r_x	I_y	S_y	r_y	Rivet Data			J
d	t														Max D	Gage	Grip	
3	.170	1.67	2.02	2.330	.170	.27	.10	1¾	2.25	1.68	1.23	.46	.39	.52	⅜	¾	5/16	.045
	.251	1.91	2.31	2.411	.170	.27	.10	1¾	2.71	1.80	1.19	.51	.42	.52	⅜	¾	5/16	.061
	.349	2.21	2.67	2.509	.170	.27	.10	1¾	2.93	1.95	1.15	.59	.47	.52	⅜	¾	5/16	.093
4	.190	2.25	2.72	2.660	.190	.29	.11	2¾	6.06	3.03	1.64	.76	.57	.58	½	¾	5/16	.074
	.253	2.50	3.03	2.723	.190	.29	.11	2¾	6.40	3.20	1.60	.82	.61	.57	½	¾	5/16	.092
	.326	2.79	3.38	2.796	.190	.29	.11	2¾	6.79	3.39	1.56	.90	.65	.57	½	¾	5/16	.12
	.400	3.09	3.74	2.870	.190	.29	.11	2¾	7.18	3.59	1.52	.99	.69	.57	½	¾	5/16	.17
5	.210	2.92	3.53	3.000	.210	.31	.13	3½	12.26	4.90	2.05	1.21	.81	.64	½	⅞	⅜	.12
	.347	3.60	4.36	3.137	.210	.31	.13	3½	13.69	5.48	1.95	1.41	.90	.63	½	⅞	⅜	.19
	.494	4.34	5.25	3.284	.210	.31	.13	3½	15.22	6.09	1.87	1.66	1.01	.62	½	⅞	⅜	.33

For key to symbols, see explanation Page 82.

Excerpt: Reynolds Aluminum Structural Design Handbook.

Table 22—STANDARD I-BEAMS (Concluded)

Size d	Thickness t	A	W	b	t_1	R_1	R_2	d_1	I_x	S_x	r_x	I_y	S_y	r_y	Rivet Data Max D	Gage	Grip	J
6	**.230**	3.66	4.43	3.330	.230	.33	.14	4½	22.08	7.36	2.46	1.82	1.09	.71	⅝	1	⅜	.17
	.343	4.34	5.25	3.443	.230	.33	.14	4½	24.11	8.04	2.36	2.04	1.19	.69	⅝	1	⅜	.24
	.465	5.07	6.13	3.565	.230	.33	.14	4½	26.31	8.77	2.28	2.31	1.30	.68	⅝	1	⅜	.38
7	**.250**	4.48	5.42	3.660	.250	.35	.15	5¼	36.69	10.48	2.86	2.63	1.44	.77	⅝	1⅛	⅜	.25
	.345	5.15	6.23	3.755	.250	.35	.15	5¼	39.40	11.26	2.77	2.88	1.53	.75	⅝	1⅛	⅜	.32
	.450	5.88	7.12	3.860	.250	.35	.15	5¼	42.40	12.12	2.69	3.17	1.64	.73	⅝	1⅛	⅜	.46
8	**.270**	5.40	6.53	4.000	.270	.37	.16	6¼	57.55	14.39	3.27	3.73	1.86	.83	¾	1⅛	7/16	.34
	.349	6.03	7.30	4.079	.270	.37	.16	6¼	60.92	15.23	3.18	3.99	1.95	.81	¾	1⅛	7/16	.42
	.441	6.77	8.19	4.171	.270	.37	.16	6¼	64.85	16.21	3.10	4.31	2.07	.80	¾	1⅛	7/16	.56
	.532	7.49	9.07	4.262	.270	.37	.16	6¼	68.73	17.18	3.03	4.66	2.19	.79	¾	1⅛	½	.75
9	**.290**	6.38	7.72	4.330	.290	.39	.17	7	85.90	19.09	3.67	5.09	2.35	.89	¾	1¼	½	.46
	.397	7.35	8.89	4.437	.290	.39	.17	7	92.40	20.53	3.55	5.54	2.50	.87	¾	1¼	½	.61
	.561	8.82	10.68	4.601	.290	.39	.17	7	102.36	22.75	3.41	6.30	2.74	.85	¾	1¼	½	.99
10	**.310**	7.45	9.01	4.660	.310	.41	.19	8	123.39	24.68	4.07	6.78	2.91	.95	¾	1⅜	½	.62
	.447	8.82	10.67	4.797	.310	.41	.19	8	134.81	26.96	3.91	7.50	3.13	.92	¾	1⅜	½	.86
	.594	10.29	12.45	4.944	.310	.41	.19	8	147.06	29.41	3.78	8.36	3.38	.90	¾	1⅜	½	1.31
12	**.350**	9.35	11.31	5.000	.350	.45	.21	9¾	218.13	36.35	4.83	9.35	3.74	1.00	¾	1½	9/16	.92
	.428	10.28	12.44	5.078	.350	.45	.21	9¾	229.36	38.23	4.72	9.87	3.89	.98	¾	1½	9/16	1.10
	.460	11.97	14.49	5.250	.460	.56	.28	9¼	272.15	45.36	4.77	13.54	5.16	1.06	¾	1½	¾	1.78
	.565	13.23	16.01	5.355	.460	.56	.28	9¼	287.27	47.88	4.66	14.50	5.42	1.05	¾	1½	¾	2.19
	.687	14.70	17.78	5.477	.460	.56	.28	9¼	304.84	50.81	4.56	15.71	5.74	1.03	¾	1¾	¾	2.85

For key to symbols, see explanation Page 82.

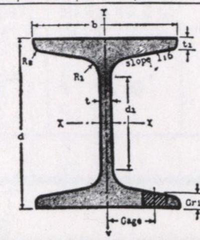


Table 23—EQUAL TEES

Size b	d	t	A	W	t_1	t_2	R_1	I_x	S_x	r_x	y_x	I_y	S_y	r_y
1	**1**	**⅛**	.267	.323	5/32	5/32	⅛	.023	.032	.293	.292	.011	.023	.206
1½	**1½**	**3/16**	.523	.633	7/32	7/32	3/16	.114	.108	.443	.437	.056	.075	.312
1½	**1½**	**¼**	.740	.895	9/32	9/32	3/16	.142	.137	.438	.464	.075	.100	.319
2	**2**	**¼**	1.07	1.29	5/16	5/16	¼	.37	.26	.59	.58	.18	.18	.41
2	**2**	**5/16**	1.28	1.55	⅜	⅜	¼	.43	.31	.58	.61	.23	.23	.42
2¼	**2¼**	**¼**	1.21	1.47	5/16	5/16	¼	.53	.33	.66	.64	.26	.23	.46
2¼	**2¼**	**5/16**	1.46	1.77	⅜	⅜	¼	.65	.41	.67	.68	.33	.29	.48
2½	**2½**	**5/16**	1.62	1.97	⅜	⅜	¼	.89	.50	.74	.73	.44	.35	.52
2½	**2½**	**⅜**	1.90	2.30	7/16	7/16	¼	1.0	.59	.74	.76	.52	.42	.53
3	**3**	**5/16**	1.98	2.40	⅜	⅜	5/16	1.58	.74	.89	.85	.75	.50	62
3	**3**	**⅜**	2.31	2.79	7/16	7/16	5/16	1.83	.86	.89	.88	.90	.60	.63
3½	**3½**	**⅜**	2.74	3.32	7/16	7/16	⅜	3.0	1.20	1.05	1.00	1.39	.80	.72
3½	**3½**	**½**	3.50	4.24	9/16	9/16	⅜	3.73	1.53	1.04	1.05	1.91	1.09	.74
4	**4**	**⅜**	3.18	3.85	7/16	7/16	½	4.56	1.58	1.20	1.11	2.12	1.06	.82
4	**4**	**½**	4.08	4.94	9/16	9/16	½	5.7	2.0	1.20	1.18	2.8	1.4	.84

For key to symbols, see explanation Page 82.

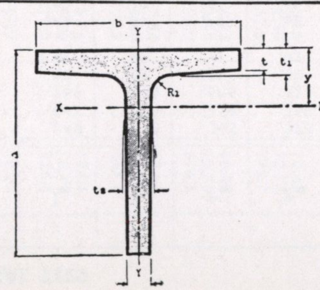


Table 24—UNEQUAL TEES

Size b	Size d	Size t	A	W	t_1	t_2	R_1	I_x	S_x	r_x	y_x	I_y	S_y	r_y
1½	1¼	⅛	.373	.451	5/32	5/32	⅛	.049	.053	.363	.326	.038	.051	.319
1½	1¼	3/16	.523	.633	7/32	7/32	⅛	.067	.075	.359	.352	.056	.075	.328
1½	2	3/16	.730	.884	¼	¼	3/16	.269	.195	.606	.624	.060	.080	.286
2½	1¼	3/16	.85	1.03	9/32	5/16	3/16	.08	.09	.31	.30	.28	.22	.57
2½	3	5/16	1.80	2.17	⅜	⅜	¼	1.49	.72	.91	.92	.44	.35	.50
3	2½	5/16	1.81	2.19	⅜	⅜	5/16	.94	.51	.72	.68	.75	.50	.65
4	2	⅜	2.30	2.78	7/16	7/16	¼	.60	.40	.51	.48	2.10	1.05	.96
4	2½	5/16	2.17	2.63	⅜	⅜	⅜	1.01	.53	.68	.60	1.77	.88	.90
4	2½	⅜	2.54	3.08	7/16	7/16	2/8	1.2	.62	.69	.62	2.1	1.0	.92
4	3	5/16	2.34	2.84	⅜	⅜	⅜	1.72	.77	.86	.75	1.77	.89	.87
4	3	⅜	2.74	3.32	7/16	7/16	⅜	2.0	.90	.86	.78	2.1	1.1	.89
4	4½	⅜	3.39	4.10	7/16	7/16	½	6.37	1.98	1.37	1.29	2.13	1.06	.79
4	4½	½	4.34	5.26	9/16	9/16	½	7.9	2.5	1.37	1.37	2.8	1.4	.81
4	5	⅜	3.59	4.34	7/16	7/16	½	8.56	2.43	1.54	1.48	2.13	1.06	.77
4	5	½	4.60	5.57	9/16	9/16	½	10.84	3.14	1.54	1.54	2.83	1.42	.79
4½	3	5/16	2.52	3.04	⅜	⅜	⅜	1.78	.78	.84	.71	2.52	1.12	1.00
5	3	⅜	3.42	4.14	7/16	⅝	⅜	2.37	1.06	.83	.76	4.13	1.65	1.10

For key to symbols, see explanation Page 82.

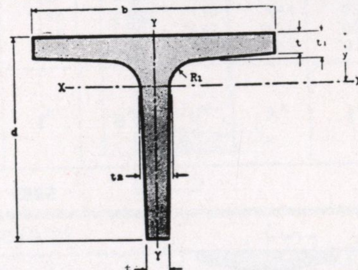
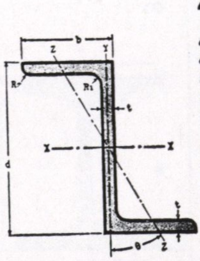


Table 25—ZEES

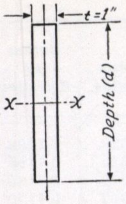
Size d	Size t	A	W	b	R_1	R_2	I_x	S_x	r_x	I_y	S_y	r_y	O_z	z	r_z	J
3	¼	1.98	2.40	2 11/16	5/16	¼	2.89	1.92	1.21	2.64	1.03	1.15	43°24′	.59	.54	.044
3 1/16	5/16	2.50	3.02	2¾	5/16	¼	3.65	2.39	1.21	3.47	1.34	1.18	44°05′	.76	.55	.087
3	⅜	2.87	3.48	2 11/16	5/16	¼	3.86	2.57	1.16	3.76	1.50	1.14	44°31′	.82	.53	.15
3 1/16	7/16	3.38	4.09	2¾	5/16	¼	4.57	2.99	1.16	4.59	1.81	1.17	45°04′	.99	.54	.24
3	½	3.70	4.48	2 11/16	5/16	¼	4.60	3.06	1.11	4.71	1.93	1.13	45°27′	1.03	.53	.35
3 1/16	9/16	4.20	5.08	2¾	5/16	¼	5.26	3.44	1.12	5.53	2.24	1.15	45°55′	1.22	.54	.51
4	¼	2.42	2.93	3 1/16	5/16	¼	6.32	3.16	1.62	4.01	1.36	1.29	36°47′	1.08	.67	.053
4 1/16	5/16	3.04	3.68	3⅛	5/16	¼	7.97	3.92	1.62	5.24	1.76	1.31	37°24′	1.39	.68	.10
4⅛	⅜	3.67	4.44	3 3/16	5/16	¼	9.66	4.68	1.62	6.54	2.18	1.33	37°55′	1.72	.68	.18
4	7/16	4.06	4.92	3 1/16	5/16	¼	9.68	4.84	1.54	6.53	2.30	1.27	37°50′	1.74	.66	.28
4 1/16	½	4.67	5.65	3⅛	5/16	¼	11.20	5.51	1.55	7.75	2.70	1.29	38°16′	2.06	.66	.43
4⅛	9/16	5.29	6.40	3 3/16	5/16	¼	12.76	6.19	1.55	9.05	3.11	1.31	38°41′	2.41	.68	.62
5	5/16	3.41	4.13	3¼	5/16	¼	13.41	5.36	1.98	5.94	1.92	1.32	30°40′	1.89	.74	.12
5 1/16	⅜	4.12	4.98	3 5/16	5/16	¼	16.23	6.41	1.99	7.40	2.37	1.34	31°08′	2.33	.75	.21
5⅛	7/16	4.83	5.84	3⅜	5/16	¼	19.12	7.46	1.99	8.95	2.84	1.36	31°32′	2.81	.76	.33
5	½	5.27	6.37	3¼	5/16	¼	19.23	7.69	1.91	8.82	2.94	1.29	31°09′	2.82	.73	.48
5 1/16	9/16	5.96	7.21	3 5/16	5/16	¼	21.87	8.64	1.92	10.28	3.39	1.31	31°32′	3.29	.74	.69
5⅛	⅝	6.66	8.05	3⅜	5/16	¼	24.56	9.59	1.92	11.82	3.86	1.33	31°53′	3.79	.75	.97
6	⅜	4.61	5.58	3½	5/16	¼	25.40	8.47	2.35	8.83	2.67	1.38	26°55′	3.08	.82	.23
6 1/16	7/16	5.40	6.54	3 9/16	5/16	¼	29.88	9.86	2.35	10.66	3.19	1.40	27°17′	3.70	.83	.37
6⅛	½	6.20	7.51	3⅝	5/16	¼	34.44	11.24	2.36	12.58	3.73	1.42	27°37′	4.36	.84	.56
6	9/16	6.69	8.10	3½	5/16	¼	34.71	11.57	2.28	12.32	3.83	1.36	27°08′	4.36	.81	.77
6 1/16	⅝	7.48	9.05	3 9/16	5/16	¼	38.93	12.84	2.28	14.15	4.35	1.38	27°26′	5.01	.82	1.07
6⅛	11/16	8.27	10.00	3⅝	5/16	¼	43.24	14.12	2.29	16.07	4.90	1.39	27°44′	5.70	.83	1.45



For key to symbols, see explanation Page 82.

Excerpt: Reynolds Aluminum Structural Design Handbook.

Table 26—RECTANGLES



All dimensions are in inches; area in square inches.

Weight in pounds per foot. I = Moment of Inertia in in.^{4}

Section Modulus: $S_{x-x} = \dfrac{I_{x-x}}{d/2}$

Radius of Gyration: $r_{x-x} = 0.289\ d$

All values listed below are for a thickness (t) of 1 inch. For other thicknesses, multiply these values by the actual thicknesses in inches, or fraction of an inch.

d Depth Inches		d—Depth (Whole Number at Left, Plus This Fraction of an Inch)							
		0	1/8	1/4	3/8	1/2	5/8	3/4	7/8
1	Wt.	1.210	1.361	1.513	1.664	1.815	1.966	2.118	2.269
	Area	1.000	1.125	1.250	1.375	1.500	1.625	1.750	1.875
	I x-x	0.083	0.119	0.163	0.217	0.281	0.358	0.447	0.549
2	Wt.	2.420	2.571	2.723	2.874	3.025	3.176	3.328	3.479
	Area	2.000	2.125	2.250	2.375	2.500	2.625	2.750	2.875
	I x-x	0.667	0.800	0.949	1.116	1.302	1.507	1.733	1.980
3	Wt.	3.630	3.781	3.933	4.084	4.235	4.386	4.538	4.689
	Area	3.000	3.125	3.250	3.375	3.500	3.625	3.750	3.875
	I x-x	2.250	2.543	2.861	3.204	3.573	3.970	4.395	4.849
4	Wt.	4.840	4.991	5.143	5.294	5.445	5.596	5.748	5.899
	Area	4.000	4.125	4.250	4.375	4.500	4.625	4.750	4.875
	I x-x	5.333	5.849	6.397	6.978	7.594	8.244	8.931	9.655
5	Wt.	6.050	6.201	6.353	6.504	6.655	6.806	6.958	7.109
	Area	5.000	5.125	5.250	5.375	5.500	5.625	5.750	5.875
	I x-x	10.420	11.220	12.060	12.940	13.860	14.830	15.840	16.900
6	Wt.	7.260	7.411	7.563	7.714	7.865	8.016	8.168	8.319
	Area	6.000	6.125	6.250	6.375	6.500	6.625	6.750	6.875
	I x-x	18.000	19.150	20.350	21.590	22.890	24.230	25.630	27.080
7	Wt.	8.470	8.621	8.773	8.924	9.075	9.226	9.378	9.529
	Area	7.000	7.125	7.250	7.375	7.500	7.625	7.750	7.875
	I x-x	28.580	30.140	31.760	33.430	35.160	36.940	38.790	40.700
8	Wt.	9.680	9.831	9.983	10.130	10.290	10.440	10.590	10.740
	Area	8.000	8.125	8.250	8.375	8.500	8.625	8.750	8.875
	I x-x	42.670	44.700	46.790	48.950	51.180	53.470	55.830	58.250
9	Wt.	10.890	11.040	11.190	11.340	11.500	11.650	11.800	11.950
	Area	9.000	9.125	9.250	9.375	9.500	9.625	9.750	9.875
	I x-x	60.750	63.320	65.950	68.660	71.450	74.310	77.240	80.250
10	Wt.	12.10	12.25	12.40	12.55	12.71	12.86	13.01	13.16
	Area	10.00	10.13	10.25	10.38	10.50	10.63	10.75	10.88
	I x-x	83.33	86.50	89.74	93.06	96.47	99.95	103.5	107.2

Table 26—RECTANGLES (Continued)

d Depth Inches		d—Depth (Whole Number at Left, Plus This Fraction of an Inch)							
		0	1/8	1/4	3/8	1/2	5/8	3/4	7/8
11	Wt.	13.31	13.46	13.61	13.76	13.92	14.07	14.22	14.37
	Area	11.00	11.13	11.25	11.38	11.50	11.63	11.75	11.88
	I x-x	110.9	114.7	118.7	122.7	126.7	130.9	135.2	139.5
12	Wt.	14.52	.....	14.82	.....	15.13	.....	15.43	.....
	Area	12.00	.....	12.25	.....	12.50	.....	12.75	.....
	I x-x	144.0	.....	153.2	.....	162.8	.....	172.7	.....
13	Wt.	15.73	.....	16.03	.....	16.34	.....	16.64	.....
	Area	13.00	.....	13.25	.....	13.50	.....	13.75	.....
	I x-x	183.1	.....	193.9	.....	205.0	.....	216.6	.....
14	Wt.	16.94	.....	17.24	.....	17.55	.....	17.85	.....
	Area	14.00	.....	14.25	.....	14.50	.....	14.75	.....
	I x-x	228.7	.....	241.1	.....	254.1	.....	267.4	.....
15	Wt.	18.15	.....	18.45	.....	18.76	.....	19.06	.....
	Area	15.00	.....	15.25	.....	15.50	.....	15.75	.....
	I x-x	281.3	.....	295.5	.....	310.3	.....	325.6	.....
16	Wt.	19.36	.....	19.66	.....	19.97	.....	20.27	.....
	Area	16.00	.....	16.25	.....	16.50	.....	16.75	.....
	I x-x	341.3	.....	357.6	.....	374.3	.....	391.6	.....
17	Wt.	20.57	.....	20.87	.....	21.18	.....	21.48	.....
	Area	17.00	.....	17.25	.....	17.50	.....	17.75	.....
	I x-x	409.4	.....	427.7	.....	446.6	.....	466.0	.....
18	Wt.	21.78	.....	22.08	.....	22.39	.....	22.69	.....
	Area	18.00	.....	18.25	.....	18.50	.....	18.75	.....
	I x-x	486.0	.....	506.5	.....	527.6	.....	549.3	.....
19	Wt.	22.99	.....	23.29	.....	23.60	.....	23.90	.....
	Area	19.00	.....	19.25	.....	19.50	.....	19.75	.....
	I x-x	571.6	.....	594.4	.....	617.9	.....	642.0	.....
20	Wt.	24.20	.....	24.50	.....	24.81	.....	25.11	.....
	Area	20.00	.....	20.25	.....	20.50	.....	20.75	.....
	I x-x	666.7	.....	692.0	.....	717.9	.....	744.5	.....
21	Wt.	25.41	.....	25.71	.....	26.02	.....	26.32	.....
	Area	21.00	.....	21.25	.....	21.50	.....	21.75	.....
	I x-x	771.8	.....	799.6	.....	828.2	.....	857.4	.....
22	Wt.	26.62	.....	26.92	.....	27.23	.....	27.53	.....
	Area	22.00	.....	22.25	.....	22.50	.....	22.75	.....
	I x-x	887.3	.....	917.9	.....	949.3	.....	981.3	.....
23	Wt.	27.83	.....	28.13	.....	28.44	.....	28.74	.....
	Area	23.00	.....	23.25	.....	23.50	.....	23.75	.....
	I x-x	1014.	.....	1047.	.....	1082.	.....	1116	.....
24	Wt.	29.04	.....	.....	.....	29.65	.....	.....	.....
	Area	24.00	.....	.....	.....	24.50	.....	.....	.....
	I x-x	1152.	.....	.....	.....	1226.	.....	.....	.....

Table 26—RECTANGLES (Concluded)

Depth		Fractions of an Inch 0	Fractions of an Inch ½	Depth		Fractions of an Inch 0	Fractions of an Inch ½
25	Wt.	30.25	30.86	**37**	Wt.	44.77	45.38
	Area	25.00	25.50		Area	37.00	37.50
	I x-x	1302.	1382.		I x-x	4221.	4395.
26	Wt.	31.46	32.07	**38**	Wt.	45.98	46.59
	Area	26.00	26.50		Area	38.00	38.50
	I x-x	1465.	1551.		I x-x	4573.	4756.
27	Wt.	32.67	33.28	**39**	Wt.	47.19	47.80
	Area	27.00	27.50		Area	39.00	39.50
	I x-x	1640.	1733.		I x-x	4943.	5136.
28	Wt.	33.88	34.49	**40**	Wt.	48.40	49.01
	Area	28.00	28.50		Area	40.00	40.50
	I x-x	1829.	1929.		I x-x	5333.	5536.
29	Wt.	35.09	35.70	**41**	Wt.	49.61	50.22
	Area	29.00	29.50		Area	41.00	41.50
	I x-x	2032.	2139.		I x-x	5743.	5956.
30	Wt.	36.30	36.91	**42**	Wt.	50.82	51.43
	Area	30.00	30.50		Area	42.00	42.50
	I x-x	2250.	2364.		I x-x	6174.	6397.
31	Wt.	37.51	38.12	**43**	Wt.	52.03	52.64
	Area	31.00	31.50		Area	43.00	43.50
	I x-x	2483.	2605.		I x-x	6626.	6859.
32	Wt.	38.72	39.33	**44**	Wt.	53.24	53.85
	Area	32.00	32.50		Area	44.00	44.50
	I x-x	2731.	2861.		I x-x	7099.	7343.
33	Wt.	39.93	40.54	**45**	Wt.	54.45	55.06
	Area	33.00	33.50		Area	45.00	45.50
	I x-x	2995.	3133.		I x-x	7594.	7850.
34	Wt.	41.14	41.75	**46**	Wt.	55.66	56.27
	Area	34.00	34.50		Area	46.00	46.50
	I x-x	3275.	3422.		I x-x	8111.	8379.
35	Wt.	42.35	42.96	**47**	Wt.	56.87	......
	Area	35.00	35.50		Area	47.00	......
	I x-x	3573.	3728.		I x-x	8652.	......
36	Wt.	43.56	44.17	**48**	Wt.	58.08	......
	Area	36.00	36.50		Area	48.00	......
	I x-x	3888.	4052.		I x-x	9216.	......

Table 26—ROUND TUBING

O. D. Inches	I. D. Inches	Wall Thickness Inches	Area Sq. In.	Weight Lb./Ft.	Moment of Inertia	Section Modulus	Radius of Gyration
.375	.305	0.035	0.0374	.0440	0.0006	0.0029	0.1208
	.277	0.049	0.0502	.0590	0.0007	0.0036	0.1166
	.259	0.058	0.0578	.0679	0.0007	0.0040	0.1140
	.245	0.065	0.0633	.0745	0.0008	0.0042	0.1120
.500	.444	0.028	0.0415	.0488	0.0012	0.0046	0.1672
	.430	0.035	0.0511	.0601	0.0014	0.0056	0.1649
	.402	0.049	0.0694	.0817	0.0018	0.0071	0.1604
	.384	0.058	0.0805	.0447	0.0020	0.0080	0.1576
	.370	0.065	0.0888	.104	0.0021	0.0086	0.1555
.625	.569	0.028	0.0525	.0618	0.0023	0.0075	0.2113
	.555	0.035	0.0649	.0763	0.0028	0.0091	0.2090
	.527	0.049	0.0887	.104	0.0037	0.0119	0.2044
	.509	0.058	0.1033	.122	0.0042	0.0134	0.2015
	.495	0.065	0.1144	.134	0.0045	0.0145	0.1993
.750	.680	0.035	0.0786	.0925	0.0050	0.0134	0.2531
	.652	0.049	0.1079	.127	0.0067	0.0178	0.2484
	.634	0.058	0.1261	.148	0.0076	0.0203	0.2455
	.620	0.065	0.1399	.165	0.0083	0.0221	0.2433
	.584	0.083	0.1739	.205	0.0098	0.0262	0.2376
.875	.805	0.035	0.0924	.109	0.0082	0.0187	0.2972
	.777	0.049	0.1272	.150	0.0109	0.0249	0.2926
	.759	0.058	0.1489	.175	0.0125	0.0285	0.2896
	.745	0.065	0.1654	.195	0.0137	0.0312	0.2873
1.00	.930	0.035	0.1061	.125	0.0124	0.0247	0.3414
	.902	0.049	0.1464	.172	0.0166	0.0331	0.3367
	.884	0.058	0.1716	.202	0.0191	0.0382	0.3337
	.870	0.065	0.1909	.225	0.0210	0.0419	0.3314
	.834	0.083	0.2391	.281	0.0253	0.0507	0.3255
	.810	0.095	0.2701	.318	0.0280	0.0559	0.3217
1.25	1.124	0.063	0.2332	0.282	0.0412	0.0659	0.4204
	1.094	0.078	0.2870	0.338	0.0491	0.0785	0.4125
	1.062	0.094	0.3405	0.402	0.0578	0.0925	0.4101
	1.000	0.125	0.4418	0.520	0.0708	0.1133	0.4002
1.50	1.374	0.063	0.2823	0.342	0.0730	0.0973	0.5087
	1.344	0.078	0.3480	0.410	0.0883	0.1180	0.5030
	1.312	0.094	0.4142	0.488	0.1028	0.1371	0.4983
	1.250	0.125	0.5400	0.635	0.1287	0.1716	0.4881
	1.188	0.156	0.6596	0.775	0.1509	0.2012	0.4783
	1.124	0.188	0.7731	0.911	0.1699	0.2265	0.4688
	1.062	0.219	0.8805	1.03	0.1859	0.2479	0.4595
	1.000	0.250	0.9817	1.15	0.1994	0.2659	0.4507
1.75	1.624	0.063	0.3313	0.400	0.1181	0.1350	0.5970
	1.594	0.078	0.4090	0.482	0.1440	0.1647	0.5930
	1.562	0.094	0.4878	0.575	0.1678	0.1918	0.5865
	1.500	0.125	0.6381	0.751	0.2119	0.2422	0.5762
	1.438	0.156	0.7823	0.919	0.2508	0.2866	0.5662
	1.374	0.188	0.9204	1.09	0.2849	0.3256	0.5564
	1.312	0.219	1.0523	1.23	0.3147	0.3597	0.5469
	1.250	0.250	1.1781	1.39	0.3405	0.3891	0.5377

Excerpt: Reynolds Aluminum Structural Design Handbook.

Table 27—ROUND TUBING (Continued)

O. D. Inches	I. D. Inches	Wall Thickness Inches	Area Sq. In.	Weight Lb./Ft.	Moment of Inertia	Section Modulus	Radius of Gyration
2.00	1.874	0.063	0.3804	0.460	0.1787	0.1787	0.6854
	1.844	0.078	0.4700	0.554	0.2160	0.2160	0.6780
	1.812	0.094	0.5614	0.662	0.2556	0.2556	0.6748
	1.750	0.125	0.7363	0.866	0.3250	0.3250	0.6644
	1.688	0.156	0.9050	1.06	0.3873	0.3873	0.6542
	1.624	0.188	1.0677	1.26	0.4431	0.4431	0.6442
	1.562	0.219	1.2241	1.44	0.4928	0.4928	0.6345
	1.500	0.250	1.3744	1.62	0.5369	0.5369	0.6250
	1.374	0.313	1.6567	1.95	0.6099	0.6099	0.6068
	1.250	0.375	1.9144	2.25	0.6656	0.6656	0.5896
	1.124	0.438	2.1476	2.53	0.7068	0.7068	0.5737
2.50	2.374	0.063	0.4786	0.579	0.3557	0.2846	0.8621
	2.344	0.078	0.5910	0.698	0.4275	0.3420	0.8500
	2.312	0.094	0.7087	0.836	0.5137	0.4110	0.8514
	2.250	0.125	0.9327	1.10	0.6594	0.5275	0.8409
	2.188	0.156	1.1505	1.35	0.7935	0.6348	0.8305
	2.124	0.188	1.3622	1.61	0.9165	0.7332	0.8202
	2.062	0.219	1.5677	1.85	1.0292	0.8234	0.8102
	2.000	0.250	1.7671	2.08	1.1321	0.9057	0.8003
	1.874	0.313	2.1476	2.54	1.3108	1.0486	0.7813
	1.750	0.375	2.5035	2.94	1.4571	1.1657	0.7629
	1.624	0.438	2.8348	3.34	1.5752	1.2602	0.7454
	1.500	0.500	3.1416	3.70	1.6690	1.3352	0.7289
3.00	2.874	0.063	0.5768	0.681	0.6224	0.4149	1.0388
	2.844	0.078	0.7140	0.842	0.7600	0.5060	1.0320
	2.812	0.094	0.8560	1.01	0.9047	0.6031	1.0280
	2.750	0.125	1.1290	1.33	1.1687	0.7791	1.0174
	2.688	0.156	1.3959	1.64	1.4153	0.9435	1.0069
	2.624	0.188	1.6567	1.95	1.6454	1.0969	0.9966
	2.562	0.219	1.9113	2.25	1.8595	1.2397	0.9864
	2.500	0.250	2.1598	2.54	2.0586	1.3724	0.9763
	2.374	0.313	2.6384	3.11	2.4143	1.6095	0.9566
	2.250	0.375	3.0925	3.64	2.7180	1.8120	0.9375
	2.124	0.438	3.5220	4.15	2.9751	1.9834	0.9191
	2.000	0.500	3.9270	4.62	3.1907	2.1271	0.9014
	1.750	0.625	4.6633	5.48	3.5157	2.3438	0.8683
	1.500	0.750	5.3014	6.24	3.7276	2.4851	0.8385
3.50	3.188	0.156	1.6414	1.93	2.2990	1.3137	1.1835
	3.000	0.250	2.5525	3.00	3.3901	1.9372	1.1524
	2.750	0.375	3.6816	4.33	4.5588	2.6050	1.1128
	2.500	0.500	4.7124	5.54	5.4487	3.1135	1.0753
4.00	3.750	0.125	1.5217	1.79	2.8591	1.4296	1.3707
	3.688	0.156	1.8867	2.22	3.4903	1.7452	1.3601
	3.562	0.219	2.5985	3.06	4.6598	2.3299	1.3391
	3.500	0.250	2.9452	3.46	5.2002	2.6001	1.3288
	3.000	0.500	5.4978	6.47	8.5903	4.2952	1.2500
	2.750	0.625	6.6268	7.79	9.7590	4.8975	1.2135
	2.500	0.750	7.6576	9.01	10.6489	5.3245	1.1793
4.50	4.124	0.188	2.5403	3.00	5.9166	2.6296	1.5261
	4.000	0.250	3.3379	3.93	7.5625	3.3611	1.5052
	3.750	0.375	4.8597	5.72	10.4217	4.6319	1.4644
	3.500	0.500	6.2832	7.39	12.7627	5.6723	1.4252
	3.000	0.750	8.8357	10.39	16.1528	7.1790	1.3520

Table 27—ROUND TUBING (Concluded)

O. D. Inches	I. D. Inches	Wall Thickness Inches	Area Sq. In.	Weight Lb./Ft.	Moment of Inertia	Section Modulus	Radius of Gyration
5.00	4.688	0.156	2.3777	2.79	6.9803	2.7921	1.7134
	4.624	0.188	2.8348	3.34	8.2192	3.2877	1.7028
	4.562	0.219	3.2858	3.87	9.4089	3.7636	1.6922
	4.500	0.250	3.7306	4.39	10.5507	4.2203	1.6817
	4.124	0.438	6.2709	7.38	16.4673	6.5869	1.6205
	4.000	0.500	7.0686	8.31	18.1132	7.2453	1.6008
	3.750	0.625	8.5903	10.10	20.9724	8.3890	1.5625
	3.500	0.750	10.0138	11.78	23.3134	9.3254	1.5258
	3.000	1.000	12.5664	14.78	26.7035	10.6814	1.4577
6.00	5.844	0.078	1.450	1.71	6.620	2.210	2.2750
	5.812	0.094	1.740	2.05	7.851	2.620	2.2452
	5.624	0.188	3.4238	4.04	14.4744	4.8248	2.0561
	5.562	0.219	3.9730	4.68	16.6224	5.5408	2.0454
	5.500	0.250	4.5160	5.31	18.6992	6.2330	2.0348
	5.374	0.313	5.5837	6.59	22.6458	7.5485	2.0139
	5.000	0.500	8.6394	10.16	33.200	10.9792	1.9526
	4.000	1.000	15.7080	18.48	51.0509	17.0170	1.8028
7.00	6.812	0.094	2.034	2.40	12.285	3.510	2.5161
	6.782	0.109	2.360	2.78	13.910	3.980	2.4250
	6.000	0.500	10.2102	12.01	54.2416	15.4976	2.3049
	5.500	0.750	14.7262	17.32	72.9408	20.8402	2.2255
8.00	7.750	0.125	3.083	3.64	24.585	6.150	2.8210
	7.688	0.156	3.8503	4.52	29.6226	7.4057	2.7737
	7.374	0.313	7.5472	8.90	55.8447	13.9612	2.7202
	7.000	0.500	11.7810	13.86	83.2031	20.8008	2.6575
	6.000	1.000	21.9912	25.87	137.4447	34.3612	2.5000
9.00	8.624	0.188	5.1910	6.28	50.4200	11.2000	3.1160
	8.500	0.250	6.8720	8.32	65.8200	14.6300	3.0950
	8.374	0.313	8.5290	10.32	80.5700	17.9100	3.0740
	8.250	0.375	10.1600	12.29	94.6700	21.0400	3.0520
	8.000	0.500	13.3500	16.16	121.0000	26.8900	3.0100
10.00	9.624	0.188	5.7800	6.99	69.5900	13.9200	3.4700
	9.500	0.250	7.6580	9.27	91.0600	18.2100	3.4480
	9.374	0.313	9.5100	11.51	111.7000	22.3400	3.4270
	9.250	0.375	11.3400	13.72	131.5000	26.3000	3.4060
	9.000	0.500	14.9200	18.06	168.8000	33.7600	3.3630
11.00	10.500	0.250	8.4430	10.22	122.0000	22.1900	3.8020
	10.374	0.313	10.4900	12.70	149.9000	27.2600	3.7800
	10.250	0.375	12.5200	15.14	176.9000	32.1600	3.7590
	10.000	0.500	16.4900	19.96	227.8000	41.4200	3.7170
12.00	11.500	0.250	9.190	10.85	160.700	26.780	4.1770
	11.250	0.375	13.660	16.11	233.300	38.800	4.1350
	11.000	0.500	18.000	21.25	300.600	50.950	4.0780
	10.500	0.750	26.400	31.18	422.000	70.250	4.0010

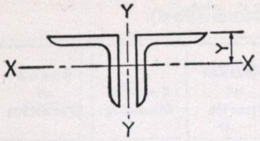


Table 28—TWO EQUAL ANGLES

Size In.	Thickness In.	Wt. Lb./Ft. 2 Angles	Area of 2 Angles Sq. In.	AXIS X-X Moment of Inertia	Section Modulus	Radius of Gyration	Y In.	RADII OF GYRATION ABOUT AXIS Y-Y — Distance Between Angles Inches 0	¼	⅜	½	⅝	¾
8x8	1⅛	40.6	33.46	195.94	35.06	2.42	2.41	3.42	3.50	3.55	3.60	3.64	3.69
	1	36.3	30.00	177.96	3 60	2.44	2.37	3.40	3.49	3.53	3.58	3.62	3.67
	⅞	32.1	26.46	159.16	28.04	2.45	2.32	3.38	3.46	3.51	3.55	3.60	3.64
	¾	27.7	22.88	139.48	24.36	2.47	2.28	3.36	3.45	3.49	3.54	3.58	3.63
	⅝	23.2	19.22	118.86	20.60	2.49	2.23	3.34	3.42	3.47	3.51	3.56	3.60
	½	18.7	15.50	97.26	16.72	2.50	2.19	3.33	3.41	3.45	3.50	3.54	3.59
6x6	1	27.6	22.00	70.92	17.14	1.80	1.86	2.59	2.68	2.72	2.77	2.82	2.87
	⅞	23.5	19.46	63.84	15.26	1.81	1.82	2.57	2.66	2.70	2.75	2.80	2.85
	¾	20.4	16.88	56.30	13.32	1.83	1.78	2.55	2.64	2.68	2.73	2.78	2.82
	⅝	17.2	14.22	48.32	11.32	1.84	1.73	2.53	2.62	2.66	2.71	2.75	2.80
	½	13.9	11.50	39.82	9.22	1.86	1.68	2.51	2.59	2.64	2.68	2.73	2.77
	⅜	10.6	8.72	30.78	7.06	1.88	1.64	2.49	2.58	2.62	2.66	2.71	2.76
5x5	1	21.8	18.00	39.28	11.60	1.48	1.61	2.19	2.28	2.33	2.38	2.42	2.47
	⅞	19.3	15.96	35.52	10.34	1.49	1.57	2.17	2.26	2.31	2.35	2.40	2.45
	¾	16.8	13.88	31.48	9.06	1.51	1.52	2.14	2.23	2.28	2.32	2.37	2.42
	⅝	14.2	11.72	27.16	7.72	1.52	1.48	2.12	2.21	2.26	2.30	2.35	2.40
	½	11.5	9.50	22.50	6.32	1.54	1.43	2.10	2.19	2.23	2.28	2.32	2.37
	⅜	8.75	7.22	17.48	4.84	1.56	1.39	2.09	2.17	2.22	2.26	2.31	2.35
4x4	¾	13.2	10.88	15.34	5.62	1.19	1.27	1.74	1.83	1.88	1.93	1.98	2.03
	⅝	11.2	9.22	13.32	4.80	1.20	1.23	1.72	1.81	1.86	1.91	1.96	2.01
	½	9.09	7.50	11.12	3.94	1.22	1.18	1.70	1.78	1.83	1.88	1.93	1.98
	⅜	6.92	5.72	8.72	3.04	1.23	1.14	1.68	1.77	1.81	1.86	1.91	1.95
	¼	4.70	3.88	6.08	2.10	1.25	1.09	1.66	1.74	1.79	1.83	1.88	1.93
3½x3½	¾	11.35	9.38	9.92	4.22	1.03	1.15	1.54	1.64	1.69	1.74	1.79	1.84
	⅝	9.65	7.96	8.66	3.62	1.04	1.10	1.52	1.61	1.66	1.71	1.76	1.81
	½	7.87	6.50	7.28	2.98	1.06	1.06	1.50	1.59	1.64	1.68	1.73	1.78
	⅜	6.02	4.96	5.74	2.30	1.07	1.01	1.48	1.56	1.61	1.66	1.70	1.75
	¼	4.09	3.38	4.02	1.58	1.09	.97	1.46	1.55	1.59	1.64	1.68	1.73
3x3	⅝	8.15	6.72	5.24	2.60	.88	.98	1.32	1.41	1.46	1.51	1.57	1.62
	½	6.66	5.50	4.44	2.14	.90	.93	1.29	1.39	1.43	1.48	1.53	1.58
	⅜	5.11	4.22	3.52	1.66	.91	.89	1.28	1.37	1.41	1.46	1.51	1.56
	¼	3.49	2.88	2.48	1.16	.93	.84	1.25	1.34	1.38	1.43	1.48	1.53
2½x2½	½	5.45	4.50	2.46	1.44	.74	.81	1.10	1.19	1.24	1.29	1.34	1.40
	⅜	4.19	3.46	1.96	1.14	.75	.76	1.07	1.16	1.21	1.26	1.31	1.36
	¼	2.88	2.38	1.40	.78	.77	.72	1.05	1.14	1.19	1.24	1.29	1.34
2x2	⅜	3.30	2.72	.96	.70	.59	.64	.87	.97	1.02	1.07	1.12	1.18
	¼	2.28	1.88	.70	.50	.61	.59	.85	.94	.99	1.04	1.09	1.14

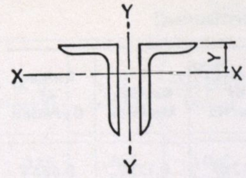


Table 29—TWO UNEQUAL ANGLES
(Long Legs Back to Back)

Size In.	Thickness In.	Wt. Lb./Ft. 2 Angles	Area of 2 Angles Sq. In.	AXIS X-X Moment of Inertia	Section Modulus	Radius of Gyration	Y In.	RADII OF GYRATION ABOUT AXIS Y-Y — Distance Between Angles Inches 0	¼	⅜	½	⅝	¾
8x6	1	31.5	26.00	161.56	30.22	2.49	2.65	2.39	2.48	2.52	2.57	2.61	2.66
	⅞	27.7	22.96	144.62	26.82	2.51	2.61	2.37	2.46	2.50	2.55	2.52	2.64
	¾	24.1	19.88	126.84	23.34	2.53	2.56	2.35	2.44	2.48	2.52	2.57	2.61
	⅝	20.2	16.72	108.20	19.74	2.54	2.52	2.34	2.42	2.46	2.51	2.55	2.60
	½	16.4	13.50	88.62	16.04	2.56	2.47	2.32	2.40	2.44	2.48	2.53	2.57
8x4	1	26.6	22.00	139.28	28.12	2.52	3.05	1.47	1.56	1.61	1.66	1.71	1.76
	⅞	23.6	19.46	124.92	24.98	2.53	3.00	1.44	1.53	1.58	1.63	1.68	1.72
	¾	20.4	16.88	109.78	21.76	2.55	2.95	1.42	1.50	1.55	1.60	1.64	1.69
	⅝	17.2	14.22	93.82	18.42	2.57	2.91	1.40	1.49	1.53	1.58	1.62	1.67
	½	13.9	11.50	76.98	14.98	2.59	2.86	1.38	1.46	1.51	1.55	1.60	1.64
7x4	1	24.2	20.00	95.46	21.70	2.18	2.60	1.53	1.62	1.67	1.72	1.77	1.82
	⅞	21.4	17.72	85.84	19.30	2.20	2.55	1.50	1.59	1.64	1.68	1.73	1.78
	¾	18.6	15.38	75.62	16.84	2.22	2.51	1.48	1.57	1.62	1.66	1.71	1.76
	⅝	15.7	12.96	64.78	14.28	2.24	2.46	1.46	1.55	1.59	1.64	1.68	1.73
	½	12.7	10.50	53.30	11.62	2.25	2.42	1.45	1.53	1.57	1.62	1.66	1.71
	⅜	9.64	7.96	41.12	8.88	2.27	2.37	1.43	1.51	1.55	1.59	1.64	1.68
6x4	⅞	19.3	15.96	55.46	14.30	1.86	2.12	1.57	1.66	1.71	1.76	1.81	1.86
	¾	16.8	13.88	49.02	12.50	1.88	2.08	1.55	1.64	1.69	1.74	1.79	1.84
	⅝	14.2	11.72	42.14	10.62	1.90	2.03	1.53	1.62	1.66	1.71	1.76	1.80
	½	11.5	9.50	34.80	8.66	1.91	1.99	1.52	1.60	1.65	1.69	1.74	1.78
	⅜	8.74	7.22	26.94	6.64	1.93	1.94	1.50	1.58	1.62	1.67	1.71	1.76
6x3½	¾	15.90	13.14	46.18	12.02	1.87	2.16	1.32	1.41	1.45	1.50	1.55	1.59
	⅝	13.4	11.10	39.70	10.18	1.89	2.11	1.30	1.39	1.43	1.48	1.53	1.58
	½	10.96	9.02	32.64	8.28	1.90	2.06	1.28	1.35	1.41	1.45	1.49	1.55
	⅜	8.30	6.86	25.20	6.30	1.92	2.00	1.27	1.34	1.39	1.44	1.48	1.53
	5/16	6.95	5.74	21.30	5.28	1.92	1.97	1.26	1.33	1.38	1.42	1.46	1.51
5x3½	¾	14.1	11.62	27.84	8.56	1.55	1.75	1.40	1.49	1.54	1.59	1.64	1.69
	⅝	11.9	9.84	24.06	7.30	1.56	1.70	1.37	1.46	1.51	1.56	1.60	1.65
	½	9.70	8.00	19.98	5.98	1.58	1.66	1.36	1.44	1.49	1.54	1.58	1.63
	⅜	7.39	6.10	15.56	4.58	1.60	1.61	1.34	1.42	1.46	1.51	1.55	1.60
5x3	13/16	14.1	11.68	.....	.....	.....	.....	1.17	1.27	1.32	1.37	1.41	1.47
	9/16	10.1	8.36	.....	.....	.....	.....	1.13	1.22	1.26	1.31	1.36	1.41
	⅜	6.90	5.70	14.30	4.30	1.59	1.68	1.08	1.16	1.21	1.26	1.30	1.36
	5/16	5.81	4.80	12.51	3.80	1.61	1.59	1.09	1.17	1.22	1.26	1.30	1.36
4x3½	¾	13.5	10.12	14.64	5.50	1.20	1.34	1.49	1.58	1.63	1.68	1.73	1.78
	⅝	10.4	8.60	12.74	4.70	1.22	1.29	1.46	1.55	1.60	1.65	1.70	1.75
	½	8.48	7.00	10.64	3.88	1.23	1.25	1.44	1.53	1.58	1.63	1.67	1.72
	⅜	6.46	5.34	8.36	2.98	1.25	1.21	1.43	1.52	1.56	1.61	1.66	1.70

Excerpt: Reynolds Aluminum Structural Design Handbook.

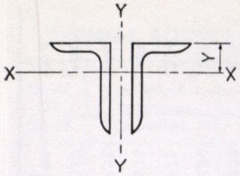


Table 29
TWO UNEQUAL ANGLES (Concluded)
(Long Legs Back to Back)

Size In.	Thick-ness In.	Wt. Lb./Ft. 2 Angles	Area of 2 Angles Sq. In.	AXIS X-X				RADII OF GYRATION ABOUT AXIS Y-Y					
				Mo-ment of In-ertia	Sec-tion Modu-lus	Radius of Gyra-tion	Y In.	Distance Between Angles Inches					
								0	¼	⅜	½	⅝	¾
4x3	⅝	9.65	7.96	12.06	4.60	1.23	1.37	1.22	1.31	1.36	1.41	1.46	1.51
	½	7.87	6.50	10.10	3.78	1.25	1.33	1.20	1.29	1.33	1.38	1.43	1.48
	⅜	6.00	4.96	7.92	2.92	1.26	1.28	1.18	1.26	1.31	1.35	1.40	1.45
	¼	4.09	3.38	5.54	2.00	1.28	1.24	1.16	1.25	1.29	1.34	1.38	1.43
3½x3	⅝	8.87	7.34	8.22	3.52	1.06	1.17	1.26	1.36	1.41	1.46	1.51	1.56
	½	7.26	6.00	6.90	2.90	1.07	1.13	1.25	1.34	1.38	1.43	1.48	1.53
	⅜	5.56	4.60	5.44	2.26	1.09	1.08	1.22	1.31	1.36	1.40	1.45	1.50
	¼	3.78	3.12	3.82	1.56	1.11	1.04	1.21	1.29	1.34	1.38	1.43	1.48
3½x2½	½	6.64	5.44	6.34	2.74	1.08	1.20	.99	1.08	1.13	1.18	1.23	1.29
	7/16	5.87	4.86	5.80	2.50	1.09	1.18	.99	1.08	1.12	1.17	1.22	1.27
	⅜	5.10	4.20	4.98	2.12	1.09	1.16	.97	1.07	1.11	1.16	1.21	1.27
	¼	3.46	2.86	3.46	1.44	1.10	1.11	.95	1.04	1.09	1.13	1.18	1.23
3x2½	½	6.04	4.98	4.06	2.02	.90	.99	1.04	1.14	1.18	1.23	1.28	1.34
	⅜	4.65	3.84	3.32	1.62	.93	.96	1.02	1.11	1.16	1.21	1.26	1.31
	¼	3.17	2.62	2.34	1.12	.95	.91	1.00	1.09	1.13	1.18	1.23	1.28
3x2	½	5.45	4.50	3.80	1.98	.92	1.07	.80	.89	.94	1.00	1.05	1.10
	⅜	4.22	3.48	3.02	1.52	.93	1.03	.78	.87	.92	.97	1.02	1.07
	5/16	3.56	2.94	2.58	1.30	.94	1.00	.77	.86	.90	.95	1.00	1.06
	¼	2.88	2.38	2.12	1.04	.94	.97	.75	.84	.89	.93	.99	1.04
	3/16	2.18	1.80	1.64	.80	.95	.94	.75	.83	.88	.93	.98	1.03
2½x2	⅜	3.75	3.10	1.82	1.10	.77	.83	.82	.91	.96	1.01	1.06	1.11
	¼	2.56	2.12	1.30	.76	.78	.79	.80	.89	.94	.99	1.04	1.09
	⅛	1.34	1.10	.68	.38	.79	.72	.78	.87	.91	.95	1.01	1.06

Table 30—COMBINATIONS, APPROXIMATE RADII OF GYRATION

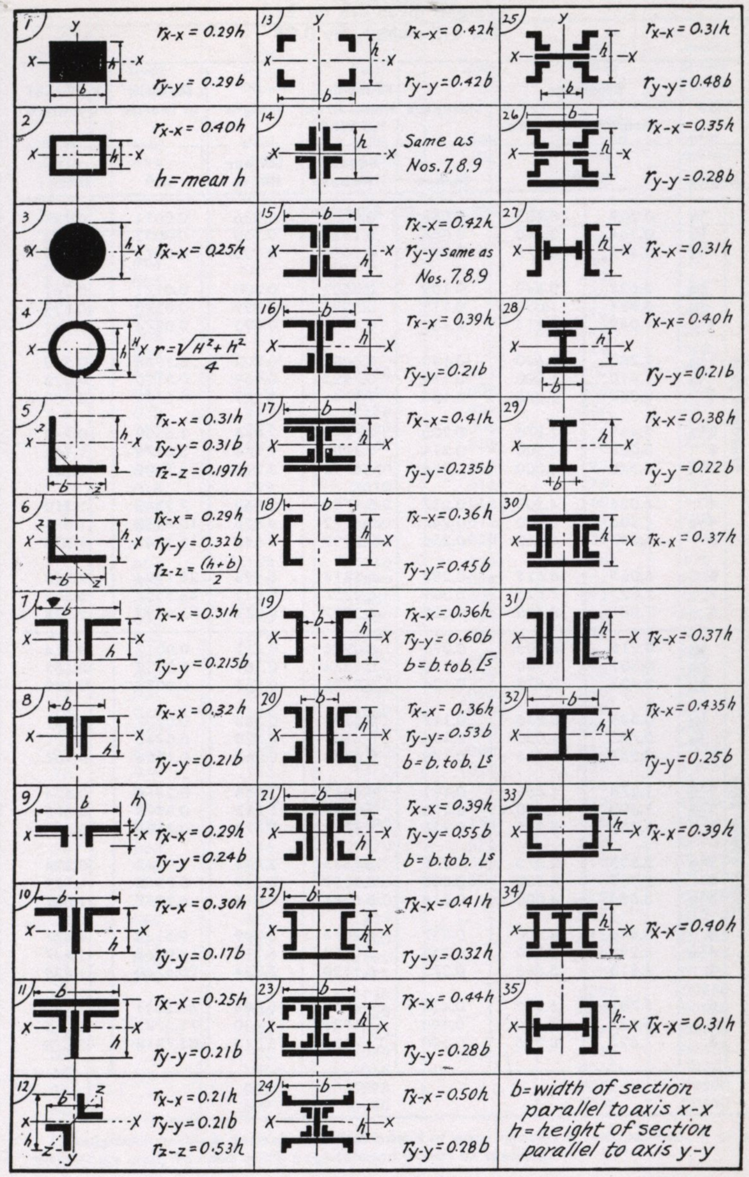
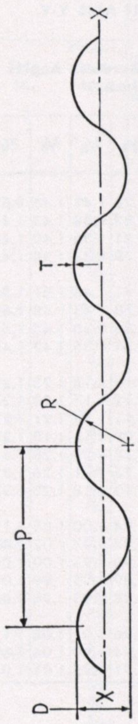


Table 31—DIMENSIONS AND ELEMENTS OF SECTIONS OF PIPE

Weights given are for 24S
For 61S multiply by 0.98

	Size	Diameter		Thickness	Cross-Sectional Area of Wall	Weight	Moment of Inertia	Radius of Gyration
		Inside	Outside					
	Inches	Inches		Inches	Square inches	Lb. per lin. ft.	In.^{4}	Inches
Standard pipe	⅛	0.269	0.405	0.068	0.0719	0.086	0.0011	0.124
	¼	0.364	0.540	0.088	0.1250	0.150	0.0033	0.163
	⅜	0.493	0.675	0.091	0.1670	0.200	0.0073	0.209
	½	0.622	0.840	0.109	0.2503	0.300	0.0171	0.261
	¾	0.824	1.050	0.113	0.3326	0.399	0.0370	0.334
	1	1.049	1.315	0.133	0 4939	0.593	0.0874	0.421
	1¼	1.380	1.660	0.140	0.6685	0.802	0.1948	0.540
	1½	1.610	1.900	0.145	0.7995	0.959	0.3100	0.623
	2	2.067	2.375	0.154	1.0745	1.289	0.6659	0.787
	2½	2.469	2.875	0.203	1.7040	2.045	1.5300	0.948
	3	3.068	3.500	0.216	2.2285	2.674	3.0179	1.164
	3½	3.548	4.000	0.266	2.6795	3.215	4.7889	1.337
	4	4.026	4.500	0.237	3.1740	3.809	7.2345	1.510
	4½	4.506	5.000	0.247	3.6882	4.426	10.4458	1.683
	5	5.047	5.563	0.258	4.2999	5 160	15.1661	1.878
	6	6.065	6.625	0.280	5.5814	6.698	28.1494	2.246
	7	7.023	7.625	0.301	6.9257	8.311	46.5187	2.592
	8	7.981	8.625	0.322	8.3992	10.079	72.4927	2.938
Extra heavy pipe	⅛	0.215	0.405	0.095	0.0925	0.111	0.0012	0.114
	¼	0.302	0.540	0.119	0.1574	0.189	0.0038	0.155
	⅜	0.423	0.675	0.126	0.2173	0.261	0.0086	0.199
	½	0.546	0.840	0.147	0.3201	0.384	0.0201	0.251
	¾	0.742	1.050	0.154	0.4335	0.520	0.0448	0.321
	1	0.957	1.315	0.179	0.6388	0.767	0.1056	0.407
	1¼	1.278	1.660	0.191	0.8815	1.058	0.2419	0.524
	1½	1.500	1.900	0.200	1.0681	1.282	0.3913	0.605
	2	1.939	2.375	0.218	1.4773	1.773	0.8681	0.767
	2½	2.323	2.875	0.276	2.2535	2.704	1.9247	0.924
	3	2.900	3.500	0.300	3.0159	3.619	3.8953	1.137
	3½	3.364	4.000	0.318	3.6784	4.414	6.2817	1.307
	4	3.826	4.500	0.337	4.4074	5.289	9.6130	1.477
	4½	4.290	5.000	0.355	5.1804	6.217	14.0568	1.647
	5	4.813	5.563	0.375	6.1120	7.334	20.6760	1.839
	6	5.761	6.625	0.432	8.4050	10.086	40.5011	2.195
	7	6.625	7.625	0.500	11.1920	13.430	71.3741	2.525
	8	7.625	8.625	0.500	12.7628	15.315	105.7218	2.878

Table 32—CORRUGATED SHEET, DIMENSIONS AND ELEMENTS OF SECTIONS



Pitch, P		Depth, D	Thickness		Weight Lb/Sq. Ft.	12-inch Width of Corrugated Sheet			
Nominal	Actual		T	R		Cross-Sectional Area Sq. In.	I_{xx} In.^{4}	S_{xx} In.^{3}	r_{xx} In.
1¼	1.263	.269	.019	9/32	.298	.251	.0021	.0156	.091
1¼	1.263	.274	.024	9/32	.376	.317	.0026	.0168	.091
2½	2.666	.519	.019	1 1/16	.295	.249	.0082	.0312	.181
2½	2.666	.524	.024	1 1/16	.373	.314	.0103	.0392	.181
2½	2.666	.875	.032	⅝	.584	.492	.0480	.1058	.313
2½	2.666	.524	.040	1 1/16	.628	.523	.0172	.0656	.188
2½	2.666	.875	.040	⅝	.738	.615	.0600	.1373	.314
2½	2.666	.524	.051	1 1/16	.800	.667	.0219	.0836	.188
2½	2.666	.875	.051	⅝	.941	.784	.0765	.1751	314.
2½	2.666	.524	.064	1 1/16	1.004	.837	0275	.1050	.188
2½	2.666	.875	.064	⅝	1.181	.984	.0960	.2197	.314

Excerpt: Reynolds Aluminum Structural Design Handbook.

Table 38
DECIMAL EQUIVALENTS OF WIRE AND SHEET METAL GAGES

NAME OF GAGE	American or Browne & Sharpe	Birmingham or Stubs Iron Wire	United States Standard	Manufacturers Standard (2)	Steel Wire or Washburn & Moen
PRINCIPLE USE	non-ferrous sheet, wire and rod	tubing, ferrous strip and flat wire, spring steel	ferrous sheet and plate (480 lb/cu ft)	ferrous sheet	ferrous wire except music wire
No.(1)	THICKNESS OR DIAMETER—Inches				
7/0	......	......	.500	......	.4900
6/0	.5800	......	.46875	......	.4615
5/0	.5165	......	.4375	......	.4305
4/0	.4600	.454	.40625	......	.3938
3/0	.4096	.425	.375	......	.3625
2/0	.3648	.380	.34375	......	.3310
0	.3249	.340	.3125	......	.3065
1	.2893	.300	.28125	......	.2830
2	.2576	.284	.265625	......	.2625
3	.2294	.259	.25	.2391	.2437
4	.2043	.238	.234375	.2242	.2253
5	.1819	.220	.21875	.2092	.2070
6	.1620	.203	.203125	.1943	.1920
7	.1443	.180	.1875	.1793	.1770
8	.1285	.165	.171875	.1644	.1620
9	.1144	.148	.15625	.1495	.1483
10	.1019	.134	.140625	.1345	.1350
11	.09074	.120	.125	.1196	.1205
12	.08081	.109	.109375	.1046	.1055
13	.07196	.095	.09375	.0897	.0915
14	.06408	.083	.078125	.0747	.0800
15	.05707	.072	.0703125	.0673	.0720
16	.05082	.065	.0625	.0598	.0625
17	.04526	.058	.05625	.0538	.0540
18	.04030	.049	.05	.0478	.0475
19	.03589	.042	.04375	.0418	.0410
20	.03196	.035	.0375	.0359	.0348
21	.02846	.032	.034375	.0329	.03175
22	.02535	.028	.03125	.0299	.0286
23	.02257	.025	.028125	.0269	.0258
24	.02010	.022	.025	.0239	.0230
25	.01790	.020	.021875	.0209	.0204
26	.01594	.018	.01875	.0179	.0181
27	.01420	.016	.0171875	.0164	.0173
28	.01264	.014	.015625	.0149	.0162
29	.01126	.013	.0140625	.0135	.0150
30	.01003	.012	.0125	.0120	.0140
31	.008928	.010	.0109375	.0105	.0132
32	.007950	.009	.01015625	.0097	.0128
33	.007080	.008	.009375	.0090	.0118
34	.006305	.007	.00859375	.0082	.0104
35	.005615	.005	.0078125	.0075	.0095
36	.005000	004	.00703125	.0067	.0090
37	.004453	......	.006640625	.0064	.0085
38	.003965	......	.00625	.0060	.0080
39	.003531	......	....	......	.0075
40	.003145	......	......	......	.0070

(1) Designation of size in decimals of an inch instead of gage numbers is recommended. If gage numbers are used, the name of the gage referred to must be specified.
(2) Recently adopted by the American Iron and Steel Institute as a modification of United States Standard Gage to reflect present average unit weights of sheet steel.

DECIMAL EQUIVALENTS OF WIRE AND SHEET METAL GAGES (Concluded)

NAME OF GAGE	Music Wire	Stubs Steel Wire	Twist Drill	Zinc	British Imperial Standard	London or Old English
PRINCIPLE USE	music wire	steel drill rod	twist drills and drill steel	sheet zinc	wire, rod, sheet and plate (British)	wire (British)
No.(1)	THICKNESS OR DIAMETER—Inches					
7/0	......	......	......	......	.500	......
6/0	.004	......	......	......	.464	......
5/0	.005	......	......	......	.432	......
4/0	.006	......	......	......	.400	.454
3/0	.007	......	......	......	.372	.425
2/0	.008	......	......	......	.348	.380
0	.009	......	......	......	.324	.340
1	.010	.227	.2280	.002	.300	.300
2	.011	.219	.2210	.004	.276	.284
3	.012	212	.2130	.006	.252	.259
4	.013	.207	.2090	.008	.232	.238
5	.014	.204	.2055	.010	.212	.220
6	.016	.201	.2040	.012	.192	.203
7	.018	.199	.2010	.014	.176	.180
8	.020	.197	.1990	.016	.160	.165
9	.022	.194	.1960	.018	.144	.148
10	.024	.191	.1935	.020	.128	.134
11	.026	.188	.1910	.024	.116	.120
12	.029	.185	.1890	.028	.104	.109
13	.031	.182	.1850	.032	.092	.095
14	.033	.180	.1820	.036	.080	.083
15	.035	.178	.1800	.040	.072	.072
16	.037	.175	.1770	.045	.064	.065
17	.039	.172	.1730	.050	.056	.058
18	.041	.168	.1695	.055	.048	.049
19	.043	.164	.1660	.060	.040	.042
20	.045	.161	.1610	.070	.036	.035
21	.047	.157	.1590	.080	.032	.0315
22	.049	.155	.1570	.090	.028	.0295
23	.051	.153	.1540	.100	.024	.0270
24	.055	.151	.1520	.125	.022	.0250
25	.059	.148	.1495	.250	.020	.0230
26	.063	.146	.1470	.375	.018	.0205
27	.067	.143	.1440	.500	.0164	.01875
28	.071	.139	.1405	1.000	.0148	.01650
29	.075	.134	.1360	......	.0136	.01550
30	.080	.127	.1285	......	.0124	.01375
31	.085	.120	.1200	......	.0116	.01225
32	.090	.115	.1160	......	.0108	.01125
33	.095	.112	.1130	......	.0100	.01025
34	......	.110	.1110	......	.0092	.00950
35	......	.108	.1100	......	.0084	.00900
36	......	.106	.1065	......	.0076	.00750
37	......	.103	.1040	......	.0068	.00650
38	......	.101	.1015	......	.0060	.00575
39	......	.099	.0995	......	.0052	.00500
40	......	.097	.0980	......	.0048	.00450

(1) Designation of size in decimals of an inch instead of gage numbers is recommended. If gage numbers are used, the name of the gage referred to must be specified.

INDEX

The text of this book was set by Westcott & Thomson, Inc., Philadelphia, Pennsylvania, in Monotype Century Expanded; headings are 12 point Foundry Clarendon; paper is Reynolds Satin Royal, basis 80, by Champion Paper Company; printed in letterpress by Davis, Delaney, Incorporated, New York; engravings by the Walker Engraving Corporation, New York.

CREDITS

CHAPTER 4

N. A. de Bruyne: Fig. 4-78, 79, 80, 81; George Epstein: 4-82.

CHAPTER 7

Overly Mfg. Co.: 7-27; Reynolds Metals Co.: 7-28, 29, 7-65; Panaview: 7-67, 68; Reynolds Metals Co.: 7-70, 71; Marmet Corp.: 7-75; Industrial Engineering Works: 7-76; Kane Mfg. Co.: 7-77; Lord and Burnham: 7-78, 79; Wasco Flashing Co.: 7-80; Blumcraft: 7-85; Pfaff and Kendall; Hubbard and Co.: 7-91; Simplex Ceiling Corp.: 7-92; Reynolds Metals Co.: 7-93; Pittsburgh Reflector Co.: 7-94; Edison Price, Inc.: 7-95, 96; Reynolds Metals Co.: 7-97; Pittsburgh Plate Glass: 7-98; Kawneer: 7-99; Hankins and Johann: 7-100; Crane Fulview Glass Door Co.: 7-101; Alumiline Corp.: 7-102; General Bronze Corp.: 7-103; Pittsburgh Plate Glass Co.: 7-104; Kawneer: 7-105, 106; Himmel Bros. Co.: 7-107; Kawneer: 7-108; Pittsburgh Plate Glass Co.: 7-109; Himmel Bros. Co.: 7-110; Natcor: 7-111; Pittsburgh Plate Glass Co.: 7-112; Kawneer: 7-113; Kawneer, and Pittsburgh Plate Glass Co.: 7-114; Kaiser Aluminum and Chemical Sales Corp.: 7-115, 116; Kawneer: 7-117; Marmet Corp.: 7-118; Sealuxe (Universal Corp.): 7-119; Construction Specialists, Inc.: 7-120; Sealuxe (Universal Corp.): 7-122; Kawneer, also Mapes Industries, and Shurtleff Co.: 7-125, 126; Detroit Steel Products Co., also R. C. Mahon Co., Truscon Steel Co., H. H. Robertson Co.: 7-127, 128; H. H. Robertson Co.: 7-129; Reynolds Metals Co.: 7-130; Lupton: 7-131; Fentron: 7-132; J. S. Thorn Co.: 7-133; Sealuxe (Universal Corp.): 7-134, 135.

CHAPTER 8

"Aluminum Piping, Where and Why It's Used" by C. B. McLaughlin—HEATING, PIPING AND AIR CONDITIONING, March and April 1948: Tables 8-1, 8-2, 8-3, 8-4, 8-5; "ALCOA Aluminum Pipe and Fittings" by Aluminum Company of America: Tables 8-6, 8-7; "Guide" The American Society of Heating and Ventilating Engineers, 1954: Tables 8-9, 8-11; "The Design of Aluminum Duct Systems" by F. W. Hutchinson, Kaiser Aluminum and Chemical Sales, Inc. 1954: Table 8-12.

Design by the Styling and Design Department; Production by the Editorial Services Department, Reynolds Metals Company, Louisville, Kentucky.

The text of this book was set by Westcott & Thomsen, Inc., Philadelphia, Pennsylvania, in Monotype Century Expanded; headings are 12 point Foundry Clarendon; paper is Reynolds Satin Royal, Basis 80, by Champion Paper Corporation; printed in letterpress by Davis, Delaney, Incorporated, New York; engravings by the Walker Engraving Corporation, New York.

CREDITS

CHAPTER 1

[illegible]

CHAPTER 2

[illegible]

CHAPTER 8

[illegible]

Design by the Styling and Design Department

Production by the Editorial Services Department

Reynolds Metals Company, Louisville, Kentucky

of exact scientific information has become an expected corporate service. The more of this kind of literature the building industry can obtain, the better it can keep its place in the modern parade."

David Allison

"Architectural Forum"

"These books document beautifully the architectural uses of aluminum—one of the few really new materials of our time. In well-chosen examples of completed work and in clear text explaining background and technical data, the authors have brought together all that a good designer needs to stimulate and direct his own creative imagination in the use of aluminum. There is even a fine group of statements by architects and engineers explaining how their imaginations *have* been stimulated."

Thomas H. Creighton

Editor

"Progressive Architecture"

"Both volumes of "Aluminum in Modern Architecture" are more than normally rewarding study experiences. Volume I is the most complete pictorial cataloging of modern American buildings anywhere published, and Volume II is without question the best and broadest collection of detailing in this ubiquitous material."

John Knox Shear

Editor

"Architectural Record"